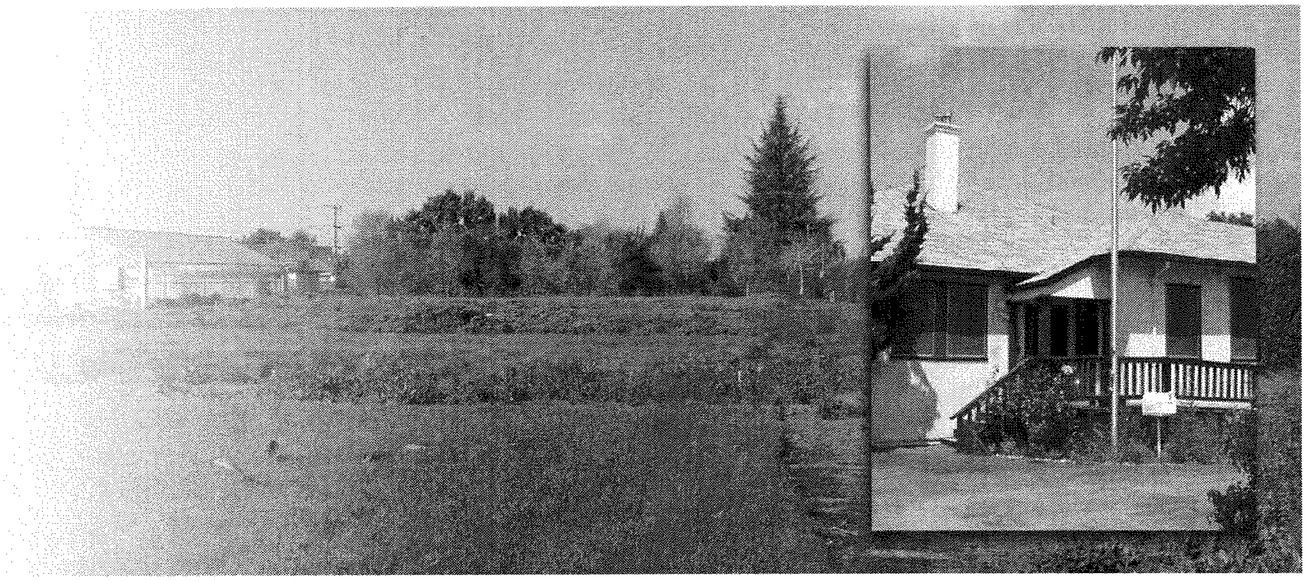
Draft Environmental Impact Report

Santa Clara Gardens Development Project



VOLUME I

DEIR Text and Appendices A, K and M

Lead Agency

City of Santa Clara

SCH #2003072093

March 9, 2006

EDAW

increases from area source emissions (i.e. landscape maintenance equipment). Therefore, operational air emissions from the All Single-Family Development Alternative would be less than significant.

Table 7-2
Carbon Monoxide Modeling Results
Under the All Single-Family Development Alternative

	Existing		Future No Alternative		Future with Alternative	
Receptor	1-hour	8-hour	1-hour	8-hour	1-hour	8-hour
1. Pruneridge Avenue/San Thomas Expressway	11.4	6.9	12.2	7.3	12.2	7.3
2. Stevens Creek/San Tomas Expressway	13.9	7.3	14.7	7.6	14.7	7.6
3. Stevens Creek/Monroe Street	12.4	6.9	13.4	7.3	13.5	7.4
California Standards	20	9.0	20	9.0	20	9.0

Notes: EMFAC2002 used to generate vehicle emission rates. CALINE4 modeling used to estimate ambient concentrations. 1-hour background concentration of 6.0 ppm and 8-hour concentration of 3.7 ppm based on data from the measuring/monitoring station in accordance with the CO protocol. A persistence factor of 0.7 was used to convert 1-hour to 8-hour concentrations.

Source: EDAW 2004

Construction-related emissions are generally short-term in duration, but can cause adverse air quality impacts. PM_{10} is the pollutant of greatest concern with respect to construction activities. PM_{10} emissions result from the generation of fugitive dust associated with a variety of construction activities, including excavation, grading, demolition, site preparation, and vehicle travel on paved and unpaved surfaces. Construction equipment also produces CO and ozone precursor emissions. These emissions are included in the emissions inventory that is the basis for regional air quality plans, and are not expected to impede attainment of ozone or maintenance of CO standards in the Bay Area.

The BAAQMD does not require that construction emissions be quantified. Rather, the significance of construction emissions should be determined based on whether BAAQMD's feasible control measures would be implemented with construction activities associated with the alternative (BAAQMD 1999). Implementation of BAAQMD control measures can result in overall reductions in fugitive dust emissions by approximately 50–75%. It is assumed that for purposes of this analysis, that the developer of this alternative would include implementation of feasible BAAQMD PM_{10} construction mitigation measures, which can result in 50–75 % reductions in fugitive dust emissions. Therefore, because all feasible BAAQMD control measures would be implemented, this alternative's PM_{10} construction-related emissions would be less than significant.

As a result of pesticide use related to past agricultural practices on the site some soils have concentrations of arsenic and dieldrin above EPA preliminary remediation goals. To implement the alternative the DGS would be required to remediate onsite soils to bring them to levels suitable for proposed uses (i.e., unrestricted residential use) before construction. Pursuant to DGS' Voluntary Cleanup Agreement (VCA) with the DTSC, DGS has prepared a RAW that identifies necessary remediation activities. Elements of the RAW include excavation and removal of onsite contaminated soils and importation of clean fill material. During these activities, disturbance of onsite soils could result in dust generation and release contaminants to the atmosphere and imported fill could contain contaminants (i.e., naturally occurring asbestos). The approved RAW would include dust control measures in compliance with BAAQMD requirements, including but not limited to: wet suppression, air monitoring and collection of meteorological data, and installation of a wind fence (50% porosity) to reduce wind speed and minimize offsite travel of dust particles. Implementation of these dust control measures would reduce the potential for nearby residents to be exposed to contaminants present in onsite soils through the air pathway to less-than-significant levels. Further, the RAW would include measures (i.e., soil testing) to prevent the importation of fill material that contains contaminants. Therefore, this would be a less-than-significant impact.

Construction of this alternative could result in odors associated with construction equipment exhaust, asphalt paving and other activities. The nearest sensitive land uses include residential development that immediately borders the north, west, and southern site boundary. These impacts would be short-term in nature, terminating after construction is complete. As such, construction-related emissions of odorous compounds would not be anticipated to result in frequent or prolonged exposure of sensitive receptors to odors. This alternative does not include the long-term operation of any major stationary source of odorous emissions. Implementation of this alternative would not generate substantial odors during construction or operation and odor impacts would be less than significant.

This alternative would result in minor increases in vehicular trips associated with the development. This alternative (200 single-family homes) would generate 165 a.m. and 226 p.m. peak-hour vehicle trips per day. These vehicle trips were entered into the URBEMIS2002 model to estimate the increase in air emissions associated with implementation of this alternative. The results of the emissions modeling are presented in Tables 7-1 and 7-2. As described in those tables, this alternative would not increase emissions of ROG, NO_x, CO, or PM_{10} above BAAQMD or California significance thresholds. Further, based on modeling results presented in Appendix B, this alternative would not result in substantial increases from area source emissions (i.e., landscape maintenance equipment). Therefore, this alternative's project-related operational air emissions would be less than significant.

This alternative would result in comparable construction-related odor and remediation related air quality impacts to the project. This alternative's operational (i.e., vehicle trips) air quality impacts would be slightly greater than the project, but would not exceed any BAAQMD or California significance thresholds. Overall, this alternative would result in less-than-significant air quality impacts, but these impacts would be slightly greater than the project's air quality impacts.

and prepared a draft RAW that identifies the necessary remediation activities to excavate and remove onsite contaminated soils. The approved RAW would require the preparation of a site Health and Safety Plan. This plan would outline measures that would be employed to protect construction workers and residents from exposure to hazardous materials during remediation activities. These measures could include, but would not be limited to installing security barriers, posting notices, limiting access to the site; air monitoring, watering, and installing wind fences. Further, development contractors would be required to comply with state health and safety standards for all demolition work. This would include compliance with OSHA and Cal-OSHA requirements regarding exposure to asbestos and lead-based paint. Because remediation activities would occur in accordance with measures outlined in the RAW and demolition activities would comply with OSHA requirements, the potential to expose construction workers and residents to safety hazards as a result of remediation and demolition activities would be less than significant.

Impact 4.6-2

Create a Significant Hazard to the Public or the Environment. *The project would not involve the routine storage, use, or transportation of any hazardous materials. The use, storage and handling of hazardous substances during remediation activities and removal of existing buildings (e.g., contaminated soils, asbestos, lead-based paint) and during construction (e.g., fuels, asphalt) would occur in accordance with the approved RAW and applicable local, state, and federal laws. Therefore, impacts related to creation of significant hazards to the public through transport, use, disposal and risk of upset would be* ***less than significant.***

As a result of pesticide use related to past agricultural practices on the site, arsenic and dieldrin concentrations in onsite soils are a potential health risk of concern. As described above, DGS has prepared a draft RAW that identifies necessary remediation activities for unrestricted residential use, including excavation and removal of onsite contaminated soils, and importation of clean fill material. The project includes measures that ensure the safe transport, use, and disposal of contaminated soil and building debris removed from the site. The development contractors would be required to comply with the approved RAW and applicable local, state, and federal laws. The RAW outlines measures for specific handling and reporting procedures for hazardous materials, and disposal of hazardous materials removed from the site at an appropriate offsite disposal facility. Analysis and mitigation measures addressing the potential release of hazardous materials into the atmosphere are addressed in Section 4.3, Air Quality, of this Draft EIR.

The project would include the construction of up to 110 single-family residences, 165 senior housing units, a 1 acre municipal park, and infrastructure typically associated with residential development. None of these uses would involve the use, storage or transport of hazardous materials on a routine basis. During construction, minor use, storage and handling of hazardous substances, including fuel and asphalt, would be expected. This would be done in accordance with applicable local, state and federal regulations, including Cal-OSHA requirements, and manufacturers' instructions. Because all activities would be in compliance with applicable laws pertaining to the handling, transport, and storage of hazardous materials, this impact would be less than significant.

4.6.3 MITIGATION MEASURES

No mitigation measures are necessary for the following less-than-significant impacts.

4.6-1: Create a Safety Hazard for Construction Workers and Adjacent Residences.

4.6-2: Create a Significant Hazard to the Public or Environment.

4.6.4 LEVEL OF SIGNIFICANCE AFTER MITIGATION

The project's hazards and hazardous materials impacts (Impact 4.6-1 and 4.6-2) would be less than significant. No mitigation is required.

4.6 HAZARDS AND HAZARDOUS MATERIALS

Past agricultural operations at the project site resulted in the potential for soils with elevated pesticide concentrations. DGS conducted extensive testing at the site to determine if project site soils pose a potential health risk to future occupants. Based on soil testing results, a number of chemicals of potential concern were identified. Some onsite soils have concentrations of arsenic and dieldrin above EPA Preliminary Remediation Goals. Because of these conditions, DGS entered into a Voluntary Cleanup Agreement (VCA) with the California Department of Toxic Substances Control (DTSC). The VCA provides the basis for DTSC to exercise regulatory control and oversight for the investigation and ultimate cleanup of contamination on the project site.

Pursuant to the VCA, DGS has prepared a draft Removal Action Workplan (RAW) that identifies necessary remediation activities for soils with arsenic concentrations above background levels and dieldrin above cleanup levels. The objectives of the RAW are to (1) minimize exposure of future site residents to surface soils containing arsenic above 20 micrograms per kilogram (mg/kg), (2) ensure the mean concentration of dieldrin in an individual field is below 30 mg/kg, and (3) leave the site in a physical condition that is compatible with single-family residential use. The project includes unrestricted residential use of the property. This use would allow future residents to pursue a normal range of activities, including gardening, without restriction.

The draft RAW includes the excavation and removal of onsite soils with arsenic concentrations greater than 20 mg/kg. These soils would be hauled to an appropriately permitted disposal facility. Approximately 5,000 to 6,000 cubic yards (cy) of soil would be excavated and removed from the site, and under worst case conditions a similar volume would be brought to the site as fill. It is possible that some of the soil excavated from the proposed senior housing parking garages could be used as fill. Confirmation soil samples would be taken at the site to ensure that arsenic and dieldrin levels do not exceed cleanup goals. DTSC must approve the draft RAW and circulate it for review by public agencies and public before its implementation. DGS would be responsible for the cleanup of onsite soils in accordance with the VCA and RAW approved by DTSC and would be required to prepare an Implementation Report. Remediation activities outlined in the RAW are elements of the project and have been evaluated throughout this Draft EIR.

The goal of the following discussion is to identify as clearly as possible the extent and type of contamination found on the site and the actions proposed to reduce impacts to the general public, construction workers, and future users of the site. The following analysis is based on a Phase I Environmental Assessment Report (Phase I) and Phase II Site Characterization Report (Phase II) prepared by Environ International Corporation (2002 and 2003). A copy of these reports are included in this Draft EIR as Appendix D and E. Copies of Phase I and II reports, including sampling results, are also on file with the City of Santa Clara Planning Department and are available for review during regular business hours. These reports were peer reviewed by Hallenbeck/Allwest in July 2003.

4.6.1 ENVIRONMENTAL SETTING

The project site is not located within ¼ mile of an existing or proposed school, nor is the site within an airport land use plan or within 2 miles of a public or private airport. Further, the project site is surrounded by urban development and therefore would not be subject to wildland fires. As such, these issues are not evaluated further in this Draft EIR. The effects of the project on emergency access routes and plans is discussed in Section 4.10, Transportation and Circulation.

The U.S. EPA's Envirofacts website database was searched to identify potential hazardous contamination sites on or near the project site. The project is not listed in the Envirofacts database as a known hazardous material contamination site. No sites within ¼ mile of the project site have the potential to create a hazardous condition on the project site or in groundwater beneath the site. Further, investigations of groundwater beneath the site revealed that no contamination was present (please refer to Section 4.8, Hydrology and Water Quality) (U.S. EPA 2003). Therefore, this issue is not addressed further in this Draft EIR.

The site has been used as an agricultural research station since the 1920s. A variety of different buildings have been present on the site, some of which have historically been used for purposes such as storage or use of small quantities of pesticides. These buildings and storage areas included greenhouses, storage sheds and the administrative building basement. The small quantities of hazardous materials previously stored on the site have been removed. The field plots and greenhouses contain shallow surface soil residues from past use of agricultural chemicals such as pesticides and herbicides.

SOIL/GROUNDWATER

Based on the results of the Phase I report (Appendix D), project site operations could have resulted in elevated pesticide concentrations in onsite soils. Arsenic and dieldrin were identified as chemicals of potential concern and these pesticides could have percolated to deeper soils and groundwater. The report recommended that soil samples and testing be conducted to determine the concentrations of contaminants in onsite soils.

The Phase I report also indicated that in 1973, an evaporation bed was installed to dispose of diluted pesticide wastes (Exhibit 4-4). The evaporation bed was located adjacent to and west of the equipment wash station, next to the pesticide shed. Use of the evaporation bed was discontinued in 1985. Soils beneath the bed were tested for the presence of pesticides. Pesticide levels in these soils were below regulatory standards and were removed from the site to minimize potential contamination risk. The Phase I report concluded that operation of the evaporation bed had a low potential to contaminate soils at the site (Environ 2002).

The Phase II report (Appendix E) evaluated whether current or past chemical and pesticide use at the site resulted in soil concentrations that pose a potential threat to human health and the environment. Over 50 soil samples were collected from onsite locations. These samples were tested for 14 chemicals and over 60 pesticides commonly used before 1979. Locations of soil samples are shown in Exhibit 4-5.

The Phase II Site Characterization was conducted under the assumption that future land use would be unrestricted (i.e., that residential development would be a possibility). Receptors that could come in contact with onsite contaminated soils include construction workers and residents. The report assumed that receptors could be exposed to onsite contaminated soils through ingestion of soil, dermal contact with soil, and inhalation of airborne particles released from soil. Inhalation would be the main concern during cleanup. Evaluation of the project's potential to release hazardous materials into the atmosphere are addressed in Section 4.3, Air Quality, of this Draft EIR.

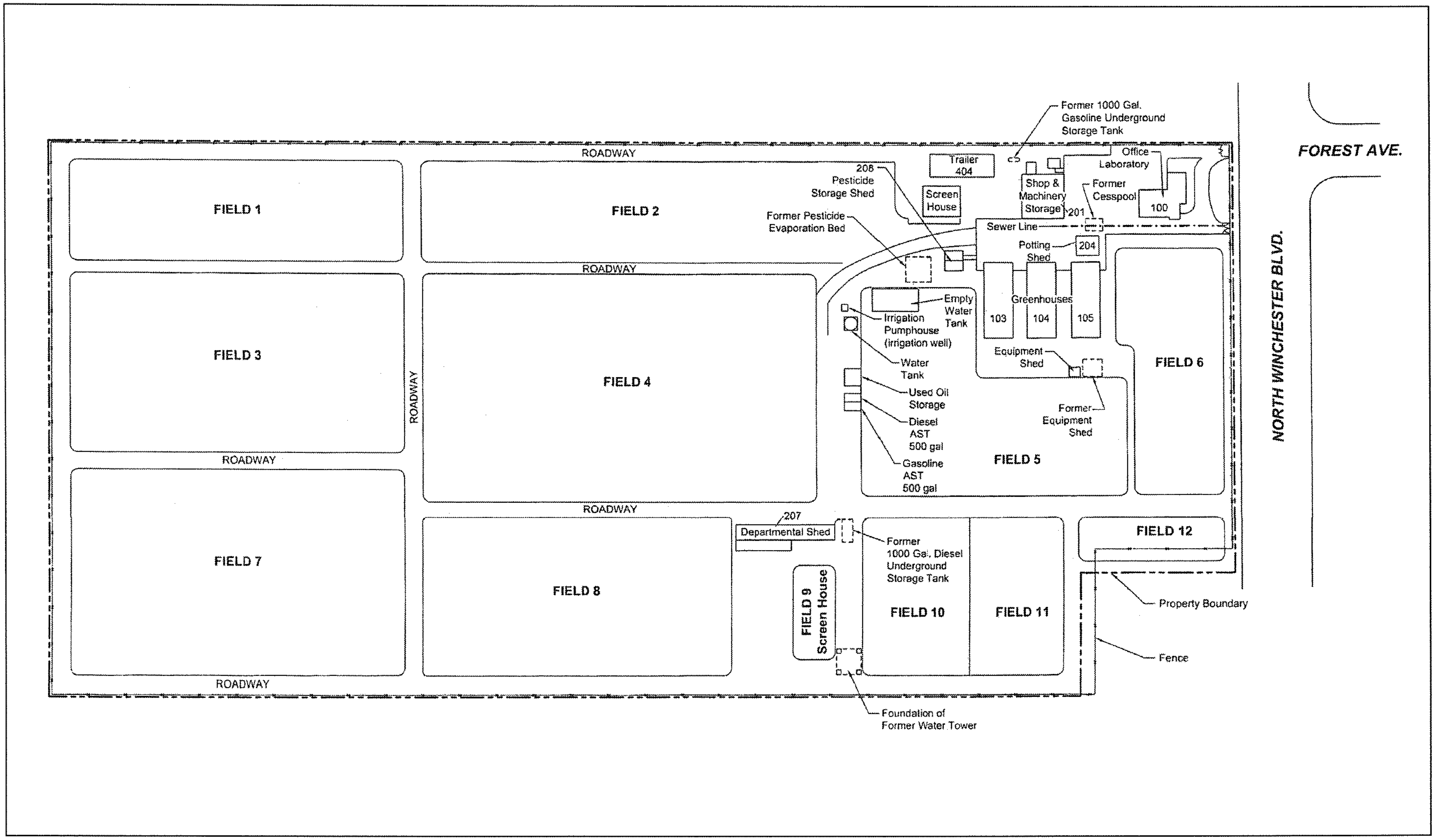
The Phase II Site Characterization indicated that arsenic and dieldrin were found in surface soils (0.5 to 3 feet below ground surface [bgs]) at concentrations above U.S. EPA Preliminary Remediation Goals (PRGs). The elevated concentrations of dieldrin found in Fields 1, 3, and 7 were isolated and limited in their horizontal and vertical extent. No remediation of dieldrin would be necessary (Environ 2003). Arsenic concentrations in shallow surface soils (i.e., 0 to 0.5 feet bgs) in the eastern portion of Field 4 were above background concentrations normally found in soils in northern Santa Clara County. In addition, elevated concentrations of arsenic were found in a small area (less than 5 square feet) adjacent to the dirt road in front of the former screen house, and in the dirt road between Fields 11 and 12. The Phase II report indicated that these arsenic concentration levels could be potentially carcinogenic to construction workers and residents and that removal of these soils would minimize potential health risks. In response, DGS entered into a VCA with the DTSC to cleanup and remove contaminated onsite soils.

SEPTIC TANK AND LEACH FIELD

Before 1977, wastewater generated in the administrative building was discharged into a sewage leach pit. The leach pit was located west of the administrative building and was abandoned in 1977 in accordance with Uniform Plumbing Code Standards for cesspools (Environ 2002). Soil samples beneath the leach pit were collected and analyzed for volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), organochlorine pesticides, total petroleum hydrocarbons (TPH), and metals/inorganics. VOCs, SVOCs, organochlorine pesticides and TPH were not detected in soil samples, but metals were found at low concentrations (Environ 2003). The metal concentrations were well within background levels for soils in the area. Therefore, there is no evidence that operation of the sewer leach pit adversely affected onsite soils or groundwater (Environ 2003).

ASBESTOS

A limited asbestos survey of project facilities was conducted in 1989. The survey found that asbestos was present in several buildings primarily in heating ducts, insulation material in bench top ovens, planter boxes, vent pipes, and hard-board bench tops (Environ 2002).



Source: Environ 9/02

Layout of the Former Research Facility

EXHIBIT 4-4

Santa Clara Gardens Development Project Draft EIR

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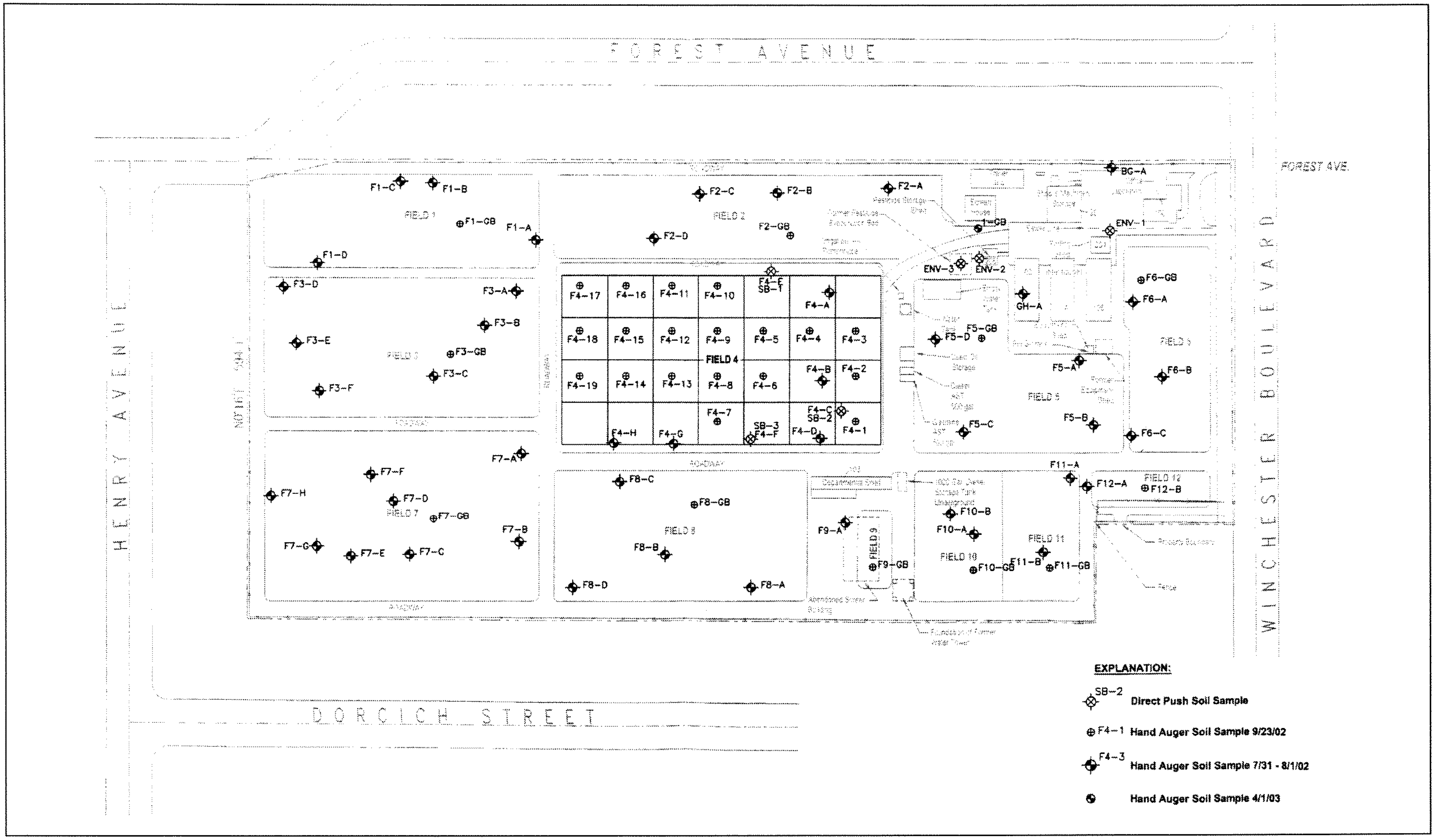

Source: Environ 4/29/03

Location of Soil Samples

EXHIBIT 4-5

Santa Clara Gardens Development Project Draft EIR

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LEAD PAINT

The use of lead as an additive to paint was discontinued in 1978. Although a lead-based paint survey was not performed at the site because site facilities were constructed before 1978, it is likely that lead-based paint is present in many of the buildings. The Phase I report recommended that the laboratory/office building be surveyed for lead-based paint if this building were to remain and could be occupied (Environ 2002).

PCBs

Several pole-mounted transformers and fluorescent light ballasts were observed on the project site. These objects may contain polychlorinated biphenyls (PCBs). The transformers were served by Pacific Gas and Electric (PG&E) which would be responsible for their removal before project construction. Fluorescent light ballasts would be removed during demolition of existing buildings.

PETROLEUM HYDROCARBONS

A 1,000-gallon gasoline underground storage tank (UST), located adjacent to the maintenance shop, and a 1,000-gallon diesel UST located adjacent to a storage building were removed from the project site in 1993. Before removal, the USTs were inspected and found to be in good condition with no evidence of leakage (i.e., stained soil, holes). Soil samples beneath the USTs were collected and analyzed for the presence of petroleum hydrocarbons. The analysis indicated that no petroleum hydrocarbons were present in soils beneath the USTs (Environ 2003).

PESTICIDE RESIDUES

The soil sample analysis results in portions of the project site indicate that 7 organochlorine pesticides, diquat, and 13 inorganic compounds were detected. A comparison of the pesticide results with U.S. EPA Region IX PRGs indicated that only dieldrin and arsenic exceeded applicable PRGs. However, dieldrin was not considered a chemical of potential concern because only 3 of 60 soil samples had concentrations above PRGs in surface soils and the concentrations were of limited horizontal and vertical extent. Therefore, dieldrin in onsite soils would not pose a significant adverse human health risk effect (Environ 2003). DGS has entered into a VCA with DTSC and prepared a draft RAW that identifies necessary remediation activity for soils contaminated with arsenic.

Radon is an odorless, invisible gas that naturally occurs in soils. Natural radon levels vary and are closely related to geologic formations. It cannot be detected without specialized equipment. Radon may enter buildings through basement sumps or other openings.

The United States Environmental Protection Agency (EPA) has established the recommended safe radon level at 4 pCi/L. The EPA has prepared a map dividing the country into three Radon Zones; Zone 1 for those areas with the average predicted indoor radon concentration in residential dwellings exceeding the EPA action limit of 4 pCi/L; Zone 2 for those areas where

IMPACT ANALYSIS

Impact 4.3-1

Construction and Remediation-Related Air Emissions. *Although implementation of the project would generate PM_{10} emissions during construction and remediation activities, the developers would implement all feasible BAAQMD PM_{10} control measures to control construction-related dust emissions at the site, and as part of the RAW for proposed remediation activities would implement dust control measures consistent with DTSC Standards to control dust and prevent the airborne exposure of soil contaminants to nearby residents. Therefore, this would be a* ***less-than-significant*** *impact.*

Construction

Construction-related emissions are generally short-term in duration, but have the potential to cause adverse air quality impacts. PM_{10} is the pollutant of greatest concern with respect to construction activities. While construction equipment and hauling of trucks emit CO and ozone precursors, these emissions are included in the emissions inventory that is the basis for regional air quality plans, and are not expected to impede attainment of ozone or maintenance of CO standards in the Bay Area. PM_{10} emissions can result from a variety of construction activities, including excavation, grading, demolition, site preparation, hauling of soil offsite, vehicle travel on paved and unpaved surfaces, and vehicle and equipment exhaust.

The BAAQMD emphasizes implementation of effective and comprehensive control measures rather than requiring a detailed quantification of construction emissions. The BAAQMD requires that all feasible control measures, which are dependent on the size of the construction area and the nature of the construction operations involved, shall be incorporated into the project design and implemented during all construction activities (BAAQMD 1999). Implementation of BAAQMD control measures reduce fugitive dust emissions by approximately 50–75%. The project applicants have agreed to implement all feasible BAAQMD-recommended control measures for construction-generated PM_{10} emissions. Therefore, short-term construction-generated PM_{10} emissions would be less than significant.

Remediation

As a result of pesticide use related to past agricultural practices on the site some soils have concentrations of arsenic and dieldrin above EPA preliminary remediation goals. To develop the site, the Department of General Services (DGS) would be required to remediate onsite soils to bring them to levels suitable for proposed uses (i.e., unrestricted residential use), before construction of any proposed buildings. Pursuant to DGS' Voluntary Cleanup Agreement (VCA) with the DTSC, DGS has prepared a RAW that identifies necessary remediation activities. Elements of the RAW include excavation and removal of onsite contaminated soils and importation of clean fill material. During these activities, disturbance of onsite soils could result in dust generation and release contaminants to the atmosphere and imported fill could contain contaminants (i.e., naturally occurring asbestos). The approved RAW would include dust control measures in compliance with BAAQMD requirements, including but not limited to: wet suppression, air monitoring and collection of meteorological data, and installation of a wind fence (50% porosity) to reduce wind speed and minimize offsite travel of dust particles. Implementation of these dust control measures would reduce the potential for nearby residents to be exposed to contaminants present in onsite soils through the air pathway to less-than-significant levels. Further, the RAW would include measures (i.e., soil testing) to prevent the importation of fill material that contains contaminants. Therefore, this would be a less-than-significant impact.

Impact 4.3-2

Exposure to Objectionable Odors. *Odors from construction activities would be intermittent and temporary in nature, and would dissipate rapidly from the source with increases in distance. In addition, no existing odor sources are located in the vicinity of the proposed project site and the project would not include the long-term operation of any new sources. Thus, the proposed project would not result in the frequent exposure of the public to objectionable odors. As a result, this impact would be considered **less than significant**.*

The occurrence and severity of odor impacts depend on numerous factors, including the nature, frequency, and intensity of the source; wind speed and direction; and the presence of sensitive receptors. While offensive odors rarely cause any physical harm, they can be unpleasant, leading to considerable distress and often generating citizen complaints to local governments and regulatory agencies.

Offensive odors can often be unpleasant, although they rarely cause long-term physical harm. The nearest sensitive land uses include residential development that immediately border the north, west, and southern site boundaries.

The construction of the proposed project would result in odors from the diesel exhaust of on-site construction equipment and asphalt paving emissions. The diesel exhaust and paving emissions would be intermittent and temporary in nature, and dissipate rapidly from the source with increases in distance. In addition, no existing odor sources are located in the vicinity of the proposed project site and the project would not include the long-term operation of any new sources. Thus, the operation of the proposed project would not result in the frequent exposure of the public to objectionable odors. As a result, this impact is considered less than significant.

Impact 4.3-3

Long-term Operational Criteria Air Pollutant Emissions. *Long-term operation of the project would not result in regional or local criteria air pollutant emissions that exceed the BAAQMD-recommended significance thresholds for ROG, NO_x, PM_{10}, or CO. Therefore, this impact would be **less than significant**.*

Long-term operation of project would result in criteria air pollutant emissions primarily from mobile (i.e., vehicle) sources. According to the transportation impact analysis, project implementation would generate a total of approximately 2,159 average daily vehicle trips (ADT) (Fehr & Peers 2005). In accordance with BAAQMD-recommended guidance, regional mobile-source emissions of ROG, NO_X, and PM_{10} associated with the operation of the project were estimated using URBEMIS 2002 Version 8.7.0 computer program, as discussed above, based on proposed land use types and number of units, project trip generation estimates from

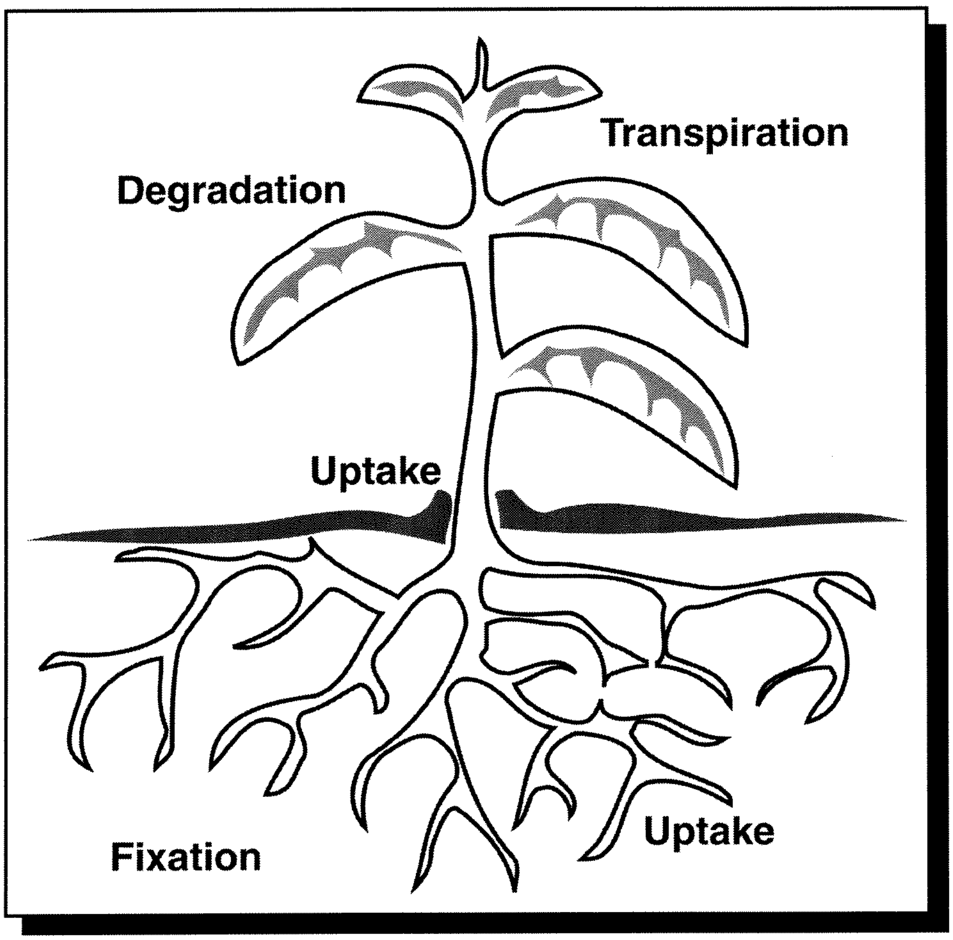
United States
Environmental Protection
Agency

Solid Waste and
Emergency Response
(5102G)

EPA 542-B-99-003
June 1999
www.epa.gov/tio
clu-in.org

EPA

Phytoremediation Resource Guide



EPA 542-B-99-003
June 1999

Phytoremediation Resource Guide

U.S. Environmental Protection Agency
Office of Solid Waste and Emergency Response
Technology Innovation Office
Washington, DC 20460

Notice

This resource guide was prepared by: Environmental Management Support, Inc., 8601 Georgia Avenue, Suite 500, Silver Spring, MD 20910 under contract 68-W6-0014, work assignments 73 and 94, with the U.S. Environmental Protection Agency. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. For more information about this project contact: Dawn Carroll, U.S. Environmental Protection Agency (5102G), Technology Innovation Office, 401 M Street, SW, Washington, DC 20460, 703-603-1234, e-mail: carroll.dawn@epa.gov.

FOREWORD

Identifying and accessing pertinent information resources that will help site cleanup managers evaluate innovative technologies is key to the broader use of these technologies. This Guide is intended to increase awareness about technical information and specialized resources related to phytoremediation technologies.

Specifically, this document identifies a cross section of information intended to aid users in remedial decision-making, including abstracts of field demonstrations, research documents, and information to assist in the ordering of publications. In addition, the look-up format of this document allows the user to quickly scan available resources and access more detailed abstracts.

Please let us know about additional information that could make this Guide (and others in the series) more useful to you. This and the other reports listed below are available to the public from the Technology Innovation Office Home Page: http://www.epa.gov/tio.

Bioremediation Resource Guide
Groundwater Treatment Technology Resource Guide
Physical/Chemical Treatment Technology Resource Guide
Soil Vapor Extraction (SVE) Enhancement Technology Resource Guide
Soil Vapor Extraction Treatment Technology Resource Guide

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INTRODUCTION

EPA is committed to identifying the most effective and efficient means of addressing the thousands of hazardous waste sites in the United States. Therefore, the Office of Solid Waste and Emergency Response's (OSWER's) Technology Innovation Office (TIO) is working in conjunction with the EPA Regions and research centers and with industry to identify and encourage the further development and implementation of innovative treatment technologies.

One way to encourage the use of these technologies is to ensure that decision-makers are aware of the most current information on technologies, policies, and other sources of assistance. This Guide was prepared to help identify documents that can directly assist Federal and State site managers, contractors, and others responsible for the evaluation of technologies. Specifically, this Guide is designed to help those responsible for the remediation of RCRA, UST, and CERCLA sites that may employ phytoremediation technologies.

This Guide provides abstracts of over 100 phytoremediation overviews, field studies and demonstrations, research articles, and Internet resources. It also provides a brief summary of phytoremediation. Finally, a matrix is also provided to allow easy screening of the abstracted references.

To develop this Guide, a literature search using relevant terms was conducted on a variety of commercial and Federal databases including:

- National Technical Information Service (NTIS)
- Energy Science and Technology
- Enviroline
- Water Resources Abstracts
- Pollution Abstracts.

In addition, Internet resources yielded numerous citations. These Internet resources include:

- U.S. Environmental Protection Agency
  http://www.epa.gov
- U.S. Army Corps of Engineers Phytoremediation Research
  http://www.wes.army.mil/EL/phyto
- U.S. Army Environmental Center
  http://aec-www.apgea.army.mil:8080
- Air Force Center for Environmental Excellence
  http://www.afcee.brooks.af.mil
- U.S. Department of Energy
  http://www.doe.gov
- U.S. Department of Agriculture
  http://www.usda.gov
- The Hazardous Waste Clean-Up Information Home Page
  http://clu-in.org
- The Ground Water Remediation Technologies Analysis Center
  http://www.gwrtac.org

- The Remediation Technologies Development Forum
  http://www.rtdf.org
- The Great Plains/Rocky Mountain Hazardous Substance Research Center
  http://www.engg.ksu.edu/HSRC
- The Phytoremediation Electronic Newsgroup Network
  http://www.dsa.unipr.it/phytonet
- The Interstate Technology and Regulatory Cooperation Working Group
  http://www.sso.org/ecos/itrc
- Battelle
  http://www.battelle.org

The selected references are not an exhaustive list of all available literature, but rather a representative sample of available print and Internet resources. For a more extensive list of phytoremediation resources, visit the Remediation Technologies Development Forum, Phytoremediation of Organics Action Team's Home Page at http://www.rtdf.org/public/phyto. The Remediation Technologies Development Forum is a public-private partnership operated by the U.S. Environmental Protection Agency. The Phytoremediation of Organics Action Team includes representatives from industry and government who share an interest in further developing and evaluating the use of plants and trees to remediate contaminated soil and water. The Action Team has compiled a bibliography containing over 1,400 citations of peer-reviewed journal articles, presentations and posters from conferences, book chapters, and articles from newspapers and magazines. The bibliography may be viewed or searched online.

Due to the inherent lag time between document publication and subsequent listing in electronic databases, there may be more recent references available than those included in the Guide. Most of the references in the Guide are of documents published between 1994 and 1998. The documents selected are available from suppliers such as EPA's National Service Center for Environmental Publications, the National Technical Information Service, document delivery services, and a variety of libraries. Descriptions of specific technologies and methodologies in this Guide does not represent an endorsement by EPA.

How to Use This Guide

When using this Guide to identify resource information on phytoremediation technologies, you may wish to take the following steps:

1. Turn to the **Phytoremediation Resource Matrix** located on pages ix through xxii of this Guide. This matrix lists all abstracted resources alphabetically by document type, identifies the type of information provided by each document, and provides a document ordering number when available. Documents in the matrix are divided into the following topical categories: general information, organic contaminants, inorganic contaminants, and Internet resources.

2. Select the documents that appear to fit your needs based on the information in the matrix.

3. Check the page number provided in the matrix. This refers to the page number of the document abstract in the Guide.

4. Review the abstract that corresponds to the document in which you are interested to confirm that the document will fit your needs.

5. If the document appears to be appropriate, note the document number highlighted under the abstract. For example:

EPA Document Number: EPA 542-R-97-004

[Note: Some documents do not have ordering numbers. These documents can be obtained through local, technical, or university libraries.]

6. Turn to the section entitled "How to Order Documents Listed in this Guide" on page vi of this Guide and order your document using the directions provided.

How to Order Documents Listed in This Guide

Documents listed in this Guide are available through a variety of sources. When ordering documents listed in the **Abstracts** section of this Guide, use the number listed in the bar below the document title, or refer to the source indicated as part of the citation. If using the **Phytoremediation Resource Matrix**, use the page number listed with the document title to refer to the complete citation and abstract. EPA 542 documents may be obtained through the National Service Center for Environmental Publications (NSCEP), and EPA 530 documents may be obtained from the RCRA Information Center (RIC). These document repositories provide in-stock documents free of charge, but document supplies may be limited. Documents obtained through the National Technical Information Service (NTIS) are available for a fee; therefore, prior to purchasing a document through NTIS, you may wish to review a copy at a technical or university library, or a public library that houses government documents.

Document Type	Document Source
Publication numbers with the following prefixes: AD DE PB	National Technical Information Service (NTIS) 5285 Port Royal Road Springfield, VA 22161 Tel: 1-800-553-NTIS Fax: (703) 605-6900 Internet: http://www.ntis.gov/

NTIS provides documents for a fee.

Publications numbers beginning with: EPA 542	National Service Center for Environmental Publications (NSCEP) P.O. Box 42419 Cincinnati, OH 45242-2419 Tel: 1-800-490-9198 Fax: (513) 489-8695 Internet: http://www.epa.gov/ncepihom/

A document title or number is needed to place an order with NSCEP.
Some out-of-stock documents may be purchased from NTIS.

Publications numbers beginning with: EPA 530	RCRA Information Center (RIC) 401 M St., SW Mailcode: 5305 Washington, DC 20460 Tel: (703) 603-9230 Fax: (703) 603-9234 Internet: http://www.epa.gov/epaoswer/general/ricorder.htm

TECHNOLOGY SUMMARY

Phytoremediation is the direct use of living plants for *in situ* remediation of contaminated soil, sludges, sediments, and ground water through contaminant removal, degradation, or containment. Growing and, in some cases, harvesting plants on a contaminated site as a remediation method is an aesthetically pleasing, solar-energy driven, passive technique that can be used to clean up sites with shallow, low to moderate levels of contamination. This technique can be used along with or, in some cases, in place of mechanical cleanup methods. Phytoremediation can be used to clean up metals, pesticides, solvents, explosives, crude oil, polycyclic aromatic hydrocarbons, and landfill leachates.

Phytoremediation has been studied extensively in research and small-scale demonstrations, but full-scale applications are currently limited in number. Further development and research of the mechanisms described below likely will lead to wider acceptance and use of phytoremediation.

Phytoremediation is a general term for several ways in which plants are used to remediate sites by removing pollutants from soil and water. Plants can degrade organic pollutants or contain and stabilize metal contaminants by acting as filters or traps. Some of the methods that are being tested are described below.

Phytoextraction Phytoextraction, also called phytoaccumulation, refers to the uptake and translocation of metal contaminants in the soil by plant roots into the aboveground portions of the plants. Certain plants called hyperaccumulators absorb unusually large amounts of metals in comparison to other plants. One or a combination of these plants is selected and planted at a site based on the type of metals present and other site conditions. After the plants have been allowed to grow for several weeks or months, they are harvested and either incinerated or composted to recycle the metals. This procedure may be repeated as necessary to bring soil contaminant levels down to allowable limits. If plants are incinerated, the ash must be disposed of in a hazardous waste landfill, but the volume of ash will be less than 10% of the volume that would be created if the contaminated soil itself were dug up for treatment.

Rhizofiltration Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone. The plants to be used for cleanup are raised in greenhouses with their roots in water rather than in soil. To acclimate the plants once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested and either incinerated or composted to recycle the contaminants.

Phytostabilization Phytostabilization is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone. This process reduces the mobility of the contaminant and prevents migration to the ground water or air, and it reduces bioavailability for entry into the food chain. This technique can be used to reestablish a vegetative cover at sites where natural vegetation is lacking due to high metal concentrations in surface soils or physical disturbances to surficial materials. Metal-tolerant species can be used to restore vegetation to the sites, thereby decreasing the potential migration of contamination through wind erosion, transport of exposed surface soils, and leaching of soil contamination to ground water.

Phytodegradation

Phytodegradation, also called phytotransformation, is the breakdown of contaminants taken up by plants through metabolic processes within the plant, or the breakdown of contaminants external to the plant through the effect of compounds (such as enzymes) produced by the plants. Pollutants are degraded, incorporated into the plant tissues, and used as nutrients.

Rhizodegradation

Rhizodegradation, also called enhanced rhizosphere biodegradation, phytostimulation, or plant-assisted bioremediation/degradation, is the breakdown of contaminants in the soil through microbial activity that is enhanced by the presence of the rhizosphere and is a much slower process than phytodegradation. Microorganisms (yeast, fungi, or bacteria) consume and digest organic substances for nutrition and energy. Certain microorganisms can digest organic substances such as fuels or solvents that are hazardous to humans and break them down into harmless products through biodegradation. Natural substances released by the plant roots—sugars, alcohols, and acids—contain organic carbon that provides food for soil microorganisms, and the additional nutrients enhance their activity. Biodegradation is also aided by the way plants loosen the soil and transport water to the area.

Phytovolatilization

Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant. Phytovolatilization occurs as growing trees and other plants take up water and the organic contaminants. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

Phytoremediation Resource Matrix

The **Phytoremediation Resource Matrix** displays summary information on references listed in the **Abstracts** section of the Guide with the exception of publications containing multiple papers. Both the **Matrix** and **Abstracts** sections are organized using the same contaminant-based categories. Internet Resources are listed in a separate matrix following printed references. The first column of the **Matrix** displays the document title, ordering number (when applicable), and page number of the full abstract in the **Abstracts** section. The second column (Technology Type) lists the technologies that the article addresses. Definitions for these technologies can be found in the Technology Summary on page vii. Column three denotes the media treated, and column four denotes the contaminants treated.

Document Title **Document Ordering Number** **[Abstract Page Number in Guide]**	**Technology Type**	**Media**		**Contaminants**				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
GENERAL INFORMATION								
The 1998 United States Market for Phytoremediation **[1]**	Unspecified	●	●	●		●		
The Advancement of Phytoremediation as an Innovative Environmental Technology for Stabilization, Remediation, or Restoration of Contaminated Sites in Canada: A Discussion Paper **[2]**	Unspecified	●	●	●		●		
Bioremediation and Phytoremediation Glossary **[2]**	Unspecified	●	●	●		●		
A Citizen's Guide to Phytoremediation **[2]** EPA 542-F-98-011	Unspecified	●	●	●	●	●		●
Compost-Enhanced Phytoremediation of Contaminated Soil **[2]** EPA 530-R-98-008	Unspecified	●		●		●		
Introduction to Phytoremediation **[2]**	Unspecified	●	●	●		●		

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Legal and Social Concerns to the Development of Bioremediation Technologies [3] DE96015254	Unspecified	●	●	●		●		
Phytoremediation [3] EPA 625-K-96-001	Unspecified	●	●	●		●		
Phytoremediation [3]	Unspecified	●	●	●		●		
Phytoremediation: A Clean Transition from Laboratory to Marketplace? [3]								
Phytoremediation: A New Technology Gets Ready to Bloom [3]	Unspecified	●	●	●		●		
Phytoremediation Bibliography [4]	Unspecified	●	●	●		●		
Phytoremediation Field Demonstrations in the U.S. EPA SITE Program [4]	Phytoextraction	●	●	●		●		
Phytoremediation: It Grows on You [4]	Unspecified	●	●	●		●		
Phytoremediation on the Brink of Commercialization [4]	Unspecified	●	●	●		●		
Phytoremediation: Technology Overview Report [5]	Unspecified	●	●	●		●		
Phytoremediation: Using Green Plants to Clean Up Contaminated Soil, Groundwater, and Wastewater [5]	Phytostabilization	●	●	●		●		
Remediation Technologies Screening Matrix and Reference Guide [5]	Unspecified	●	●	●		●		

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Stemming the Toxic Tide [5]	Phytoextraction	●	●	●		●		
Technology Evaluation Report: Phytoremediation [6]	Unspecified	●	●	●		●		
Using Phytoremediation to Clean Up Contamination at Military Installations [6] DE97007971	Unspecified	●	●	●		●		●

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
ORGANIC CONTAMINANTS								
Overviews								
Mechanisms of Phytoremediation: Biochemical and Ecological Interactions Between Plants and Bacteria [7]	Rhizodegradation	●		●				
Phytoremediation of TCE in Groundwater Using *Populus* [8]	Phytodegradation Phytovolatilization		●	●				
Field Studies and Demonstrations								
Demonstration Plan for Phytoremediation of Explosive-Contaminated Groundwater in Constructed Wetlands at Milan Army Ammunition Plant, Milan, Tennessee. Volumes 1 and 2. Final Report [8] ADA311121/8/XAB, ADA311122/6/XAB	Phytodegradation		●					●
Evaluation of Various Organic Fertilizer Substrates and Hydraulic Retention Times for Enhancing Anaerobic Degradation of Explosives-Contaminated Groundwater While Using Constructed Wetlands at the Milan Army Ammunition Plant, Milan, Tennessee [8] ADA349293	Phytodegradation		●					●
Field Scale Evaluation of Grass-Enhanced Bioremediation of PAH Contaminated Soils [8]	Rhizodegradation	●		●				
Friendly Forests [9]	Phytostabilization Phytodegradation Rhizodegradation	●	●	●				

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Groundwater Phytoremediation Test Facility, University of Washington [9]	Rhizofiltration		●	●				
Phreatophyte Influence on Reductive Dechlorination in a Shallow Aquifer Containing TCE [9]	Rhizodegradation		●	●				
Phytoremediation of Dissolved-Phase Trichloroethylene Using Mature Vegetation [10]	Phytovolatilization		●	●				
Phytoremediation of Groundwater at Avesta Sheffield Pipe [10]	Unspecified		●	●	●			
Phytoremediation of Organic and Nutrient Contaminants [10]	Phytodegradation	●	●	●	●			
Pilot-Scale Use of Trees to Address VOC Contamination [10]	Phytodegradation		●	●				
Screening of Aquatic and Wetland Plant Species for Phytoremediation of Explosives-Contaminated Groundwater from the Iowa Army Ammunition Plant. Final Report [10] ADA322455/7/XAB	Phytodegradation		●					●
Screening Submersed Plant Species for Phytoremediation of Explosives-Contaminated Groundwater from the Milan Army Ammunition Plant, Milan, Tennessee. Final Report [11]	Phytodegradation		●					●
Research								
Adsorption of Naphthalene onto Plant Roots [11]	Phytostabilization	●		●				
Aromatic Nitroreduction of Acifluorfen in Soils Rhizospheres and Pure Cultures of Rhizobacteria [11]	Rhizodegradation	●			●			

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Bacterial Inoculants of Forage Grasses that Enhance Degradation of 2-Chlorobenzoic Acid in Soil **[11]**	Rhizodegradation	●		●				
Bioremediation Bacteria to Protect Plants in Pentachlorophenol-Contaminated Soil **[12]**	Rhizodegradation	●		●				
Decreased Transpiration in Popular Trees Exposed to 2,4,6-Trinitrotoluene **[12]**	Phytovolatilization		●					●
Degradation of Polychlorinated Biphenyls by Hairy Root Culture of *Solanum nigrum* **[12]**	Phytodegradation	●		●				
Detoxification of Phenol by the Aquatic Angiosperm, *Lemna gibba* **[12]**	Phytodegradation		●	●				
Effect of Hybrid Poplar Trees on Microbial Populations Important to Hazardous Waste Bioremediation **[13]**	Rhizodegradation	●		●	●			
Effects of Ryegrass on Biodegradation of Hydrocarbons in Soil **[13]**	Rhizodegradation	●		●				
A Field Facility for Phytoremediation Research **[13]**	Phytodegradation	●		●				●
Greenhouse Evaluation of Agronomic and Crude Oil-Phytoremediation Potential Among Alfalfa Genotypes **[13]**	Phytodegradation	●		●				
The Influence of Planting and Soil Characteristics on Mineralization of 2,4,5-T in Rhizosphere Soil **[14]**	Rhizodegradation	●		●				
Mineralization of 2,4-Dichlorophenol by Ectomycorrhizal Fungi in Axenic Culture and in Symbiosis with Pine **[14]**	Rhizodegradation	●		●				

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Phytoremediation Experimentation with the Herbicide Bentazon [14]	Phytodegradation		●		●			
Phytoremediation: Modeling Removal of TNT and Its Breakdown Products [14]	Phytodegradation		●					●
Phytoremediation of 1,4-dioxane by Hybrid Poplars [14]	Phytovolatilization Rhizodegradation	●		●				
Phytoremediation of Hazardous Wastes [15]	Phytodegradation		●	●				●
Phytoremediation of Organic Contaminants: A Review of Phytoremediation Research at the University of Washington [15]	Phytodegradation	●	●	●				
Phytoremediation of Pesticide-Contaminated Soils [15]	Rhizodegradation	●			●			
Phytoremediation of Trichloroethylene with Hybrid Poplars [16]	Rhizofiltration		●	●				
Phytoremediation, Plant Uptake of Atrazine and Role of Root Exudates [16]	Rhizodegradation	●			●			
Phytotreatment of TNT-Contaminated Groundwater [16]	Phytodegradation		●					●
Plant Cell Biodegradation of a Xenobiotic Nitrate Ester, Nitroglycerin I [16]	Phytodegradation		●					●
Plant-Enhanced Remediation of Petroleum Contaminated Soil [17]	Phytodegradation Rhizodegradation	●		●				
Plant-Enhanced Subsurface Bioremediation of Nonvolatile Hydrocarbons [17]	Rhizodegradation	●		●				

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Potential of Phytoremediation as a Means for Habitat Restoration and Cleanup of Petroleum Contaminated Wetlands [17]	Phytodegradation	●		●				
Rhizosphere Microbial Populations in Contaminated Soils [17]	Rhizodegradation	●		●				
Transformation of TNT by Aquatic Plants and Plant Tissue Cultures [18]	Phytodegradation		●					●
Uptake and Fate of Organohalogens from Contaminated Groundwater in Wood Plants [18]	Phytodegradation Phytovolatilization		●	●				

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
INORGANIC CONTAMINANTS								
Overviews								
Emerging Technologies for the Remediation of Metals in Soils: Phytoremediation **[18]**	Unspecified	●				●		
Literature Review: Phytoaccumulation of Chromium, Uranium, Plutonium in Plant Systems **[19]**	Phytoextraction	●				●	●	
Remediation of Metal-Contaminated Sites Using Plants **[19]**	Phytoextraction	●				●		
Restoration of Mined Lands—Using Natural Processes **[19]**	Unspecified	●				●		
Status of *In Situ* Phytoremediation Technology **[19]** EPA 542-R-97-004	Phytoextraction Phytostabilization Rhizofiltration	●				●		
Field Studies and Demonstrations								
Phytoaccumulation of Trace Elements by Wetlands Plants: *I. Duckweed* **[20]**	Phytoextraction		●			●		
Relationship Between Sulfur Speciation in Soils and Plant Availability **[20]**	Phytoextraction	●				●		
Removal of Uranium from Water Using Terrestrial Plants **[20]**	Rhizofiltration		●			●		
Research								
Differences in Root Uptake of Radiocesium by 30 Plant Taxa **[20]**	Phytoextraction	●					●	

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Enhanced Accumulation of Pb in Indian Mustard by Soil-Applied Chelating Agents **[21]**	Phytoextraction	●				●		
Evaluation of Tamarisk and Eucalyptus Transpiration for the Application of Phytoremediation **[21]**	Phytoextraction		●			●		
Feasibility of Using Plants to Assist in the Remediation of Heavy Metal Contamination at J-Field, Aberdeen Proving Ground, Maryland. Final Report **[21]**	Phytoextraction	●				●		
Lead-Contaminated Sediments Prove Susceptible to Phytoremediation **[21]**	Phytoextraction	●				●		
Lead Uptake and Effects on Seed Germination and Plant Growth in a Pb Hyperaccumulator *Brassica pekinensis Rupr.* **[22]**	Phytoextraction	●				●		
Metal Accumulation by Aquacultured Seedlings of Indian Mustard **[22]**	Phytoextraction		●			●		
Phytoextraction of Cadmium and Zinc from a Contaminated Soil **[22]**	Phytoextraction	●				●		
Phytoextraction of Zinc by Oat (*Avena sativa*), Barley (*Hordeum vulgare*), and Indian Mustard (*Brassica juncea*) **[23]**	Phytoextraction	●				●		
Phytoextraction: the Use of Plants to Remove Heavy Metals from Soils **[23]**	Phytoextraction	●				●		
Phytofiltration of Hazardous Cadmium, Chromium, Lead and Zinc Ions by Biomass of *Medicago sativa* (Alfalfa) **[23]**	Rhizofiltration		●			●		

Document Title Document Ordering Number [Abstract Page Number in Guide]	Technology Type	Media		Contaminants				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Phytoremediation of a Radiocesium-Contaminated Soil: Evaluation of Cesium^{137} Bioaccumulation in the Shoots of Three Plant Species **[23]**	Phytoextraction	●					●	
Phytoremediation of Lead-Contaminated Soils: Role of Synthetic Chelates in Lead Phytoextraction **[24]**	Phytoextraction	●				●		
Phytoremediation of Selenium Laden Soils: A New Technology **[24]**	Phytoextraction	●				●		
Phytoremediation of Uranium-Contaminated Soils: Role of Organic Acids in Triggering Uranium Hyperaccumulation in Plants **[24]**	Phytoextraction	●					●	
Potential for Phytoextraction of ^{137}Cs from a Contaminated Soil **[25]**	Phytoextraction	●					●	
Potential Remediation of ^{137}Cs and ^{90}Sr Contaminated Soil by Accumulation in Alamo Switchgrass **[25]**	Phytoextraction	●					●	
Rhizofiltration: the Use of Plants to Remove Heavy Metals from Aqueous Streams **[25]**	Rhizofiltration		●			●		
The Role of EDTA in Pb Transport and Accumulation by Indian Mustard **[25]**	Phytoextraction		●			●		
A Search for Lead Hyperaccumulating Plants in the Laboratory **[26]**	Rhizofiltration Phytoextraction		●			●		
Selenium Accumulation by *Brassica Napus* Grown in Se-laden Soil from Different Depths of Kersterson Reservoir **[26]**	Phytoextraction	●				●		

Document Title **Document Ordering Number** **[Abstract Page Number in Guide]**	**Technology Type**	**Media**		**Contaminants**				
		Soil	Ground Water	Organics	Pesticides/ Herbicides	Metals	Radionuclides	Explosives
Test Plan for the Phytoremediation Studies of Lead-Contaminated Soil from the Sunflower Army Ammunition Plant, Desoto, Kansas. Vol. 1 and Vol. 2 **[26]** ADA342667, ADA342668	Phytoextraction	●				●		
Toxicity of Zinc and Copper to *Brassica* Species: Implications for Phytoremediation **[26]**	Phytoextraction Phytostabilization		●			●		
Toxic Mercury Reduction and Remediation Using Transgenic Plants with a Modified Bacterial Gene **[27]**	Phytoextraction Phytostabilization					●		
Zinc and Cadmium Accumulation in the Hyperaccumulator *Thlaspi Caerulescens* in Response to Limestone and Compost Applications to a Heavy Metal Contaminated Site in Palmerton, Pennsylvania **[27]**	Phytoextraction	●				●		

Web Site Title URL [Abstract Page Number in Guide]	Media		Contaminants	
	Soil	Ground Water	Organics	Inorganics
INTERNET RESOURCES				
Advanced Applied Technology Demonstration Facility (AATDF) http://www.ruf.rice.edu/~aatdf **[27]**	●		●	
Air Force Center for Environmental Excellence (AFCEE) http://www.afcee.brooks.af.mil **[27]**	●			●
Alternative Treatment Technology Information Center (ATTIC) http://www.epa.gov/attic **[28]**	●	●	●	●
CLU-IN: Hazardous Waste Clean-Up Information http://clu-in.org **[28]**	●	●	●	●
Environmental Security Technology Certification Program (ESTCP) http://www.estcp.org **[28]**	●	●	●	●
Federal Remediation Technologies Roundtable http://www.frtr.gov **[28]**	●	●	●	●
GNET: The Global Network of Environment and Technology http://www.gnet.org **[28]**				
Great Plains/Rocky Mountain Hazardous Substance Research Center http://www.ecc.ksu.edu/HSRC **[28]**	●	●	●	
Ground Water Remediation Technologies Analysis Center (GWRTAC) http://www.gwrtac.org **[29]**	●	●	●	●

Web Site Title URL **[Abstract Page Number in Guide]**	Media		Contaminants	
	Soil	Ground Water	Organics	Inorganics
Innovative Treatment Remediation Demonstration (ITRD) http://www.em.doe.gov/itrd **[29]**		●	●	●
Interstate Technology and Regulatory Cooperation Working Group (ITRC) http://www.sso.org/ecos/itrc **[29]**	●			●
PHYTONET - Phytoremediation Electronic Newsgroup Network http://www.dsa.unipr.it/phytonet **[29]**	●	●	●	●
Remediation Technologies Development Forum (RTDF) Phytoremediation of Organics Action Team http://www.rtdf.org/public/phyto **[29]**	●	●	●	
Strategic Environmental Research and Development Program (SERDP) http://www.serdp.gov **[30]**	●		●	
U.S. Army Corps of Engineers Phytoremediation Research http://www.wes.army.mil/EL/phyto **[30]**		●	●	
U.S. Army Environmental Center (USAEC) http://aec-www.apgea.army.mil:8080 **[30]**	●	●	●	●
U.S. Department of Agriculture (USDA) http://www.usda.gov **[29]**	●	●	●	●

Abstracts of Phytoremediation Resources

The resources below describe the contents of pertinent phytoremediation documents and Internet resources. The references and resources are organized alphabetically within each of the following categories:

To quickly identify documents and resources pertinent to your interest area, see the **Phytoremediation Resource Matrix** on pages ix-xxii of this Guide. The documents and resources in the matrix are organized alphabetically within the categories identified above. Listings in the matrix can be cross-referenced with the abstracts by referring to the page number provided in the matrix. In an effort to limit the number of resources listed here, documents published prior to 1990 are not included. These abstracts were obtained from several databases, including the National Technical Information Service, Energy Science and Technology, Enviroline, Water Resources Abstracts, and Pollution Abstracts as well as several Internet resources.

General Information

The 1998 United States Market for Phytoremediation
Glass, D.J.
D. Glass Associates, Inc., Needham, MA 140 pp April 1998

Phytoremediation, the use of plants, trees, and other vegetation to remove, sequester, or degrade environmental contaminants, has attracted a great deal of interest in recent years. Drawing on the abilities of plants to accumulate metals and other substances or take up and transpire large amounts of water, phytoremediation is an effective, low-cost treatment technology that is beginning to gain the attention of private and industrial site owners, regulators, and the environmental engineering community. This report includes a technology summary, commercial company profiles, research group profiles, an industry analysis and market forecast, summaries of several completed and ongoing phytoremediation projects, a review of the advantages and disadvantages of the technology, and a glossary.

The Advancement of Phytoremediation as an Innovative Environmental Technology for Stabilization, Remediation, or Restoration of Contaminated Sites in Canada: A Discussion Paper
McIntyre, T. and Lewis, G.M.
Journal of Soil Contamination v 6:3 p 227(15) May 1997

Environment Canada's Environmental Technologies Advancement Division is exploring the potential of phytoremediation as a major, long-term technology approach. The benefits and limitations of phytoremediation and its potential for bioremediation of soil and ground water in Canada are discussed. Research issues that will need to be addressed to further phytoremediation technology are examined. Other regulatory, legal, commercial, and social issues are considered briefly.

Bioremediation and Phytoremediation Glossary
Bentjen, S.
Available at
http://members.tripod.com/~bioremediation

This glossary lists terms related to bioremediation (microbial degradation) and phytoremediation (remediation using green plants) of environmental pollutants. Links to other environmental glossaries appear at the bottom of the page.

A Citizen's Guide to Phytoremediation
U.S. EPA, Office of Solid Waste and Emergency Response
6 pp August 1998
Available at http://clu-in.org

EPA Document Number: EPA 542-F-98-011

EPA's Technology Innovation Office has published a Technology Fact Sheet that describes what phytoremediation is, how it works, what its limitations are, and where to find additional information.

Compost-Enhanced Phytoremediation of Contaminated Soil
U.S. EPA, Office of Solid Waste and Emergency Response
Published in *Analysis of Composting as an Environmental Remediation Technology* p 87(12)
April 1998

EPA Document Number: EPA 530-R-98-008

Phytoremediation is a developing technology in which higher plants and microorganisms associated with plant roots are the active agents for uptake and/or degradation of toxic inorganic and organic compounds in soil and water. Plants can also provide containment by reducing the erosional transport of contaminated soil. Numerous reports indicate that plants can take up and degrade toxic organic compounds in soil, while other work indicates microorganisms in the rhizosphere are very competent degraders of soil-borne organics. This process might be suitable for soil remediation and/or inexpensive confinement of shallow contaminated water. Phytoremediation of metal-contaminated soil relies on the ability of plants to accumulate metals at concentrations substantially above those found in the soil in which they grow. Phytoremediation has very large economic advantages over mechanically intensive technologies.

Introduction to Phytoremediation
U.S. EPA, National Risk Management Research Laboratory
To be issued in 1999
To be available at http://www.rtdf.org

This handbook is the work of the EPA Phytoremediation Handbook Team in conjunction with the Remediation Technologies Development Forum (RTDF) Phytoremediation Action Team. It was developed to provide a tool for site regulators, owners, neighbors, and managers to evaluate the applicability of phytoremediation to a site. Phytoremediation projects have been proposed or applied to ecosystem restoration and soil, surface water, ground water, and sediment remediation. This document identifies, defines, and provides a framework to evaluate these phytoremediation applications, although it is not a design guide. It also presents case studies illustrating field applications of phytoremediation.

Legal and Social Concerns to the Development of Bioremediation Technologies
Bilyard, G.R.; et al.
150 pp Sep 1996

NTIS Document Number: DE96015254

The social and legal framework within which bioremediation technologies must be researched, developed, and deployed in the U.S. are discussed in this report. Discussions focus on policies, laws and regulations, intellectual property, technology transfer, and stakeholder concerns. These discussions are intended to help program managers, scientists and engineers understand the social and legal framework within which they work, and be cognizant of relevant issues that must be navigated during bioremediation technology research, development, and deployment activities. While this report focuses on the legal and social environment within which the DOE operates, the laws, regulations and social processes could apply to other sites nationwide. This report identifies specific issues related to bioremediation technologies, including those involving the use of plants; native, naturally occurring microbes; non-native, naturally occurring microbes; genetically engineered organisms; and microbial products (e.g., enzymes, surfactants, chelating compounds).

Phytoremediation
Rock, S. and Pope, D.
Published in *Seminars: Bioremediation of Hazardous Waste Sites: Practical Approaches to Implementation* p 8.1(9) 1996

EPA Document Number: EPA 625-K-96-001

Chapter eight of the seminar publication contains a description of the different aspects of phytoremediation, applications and examples, a bibliography, and illustrations from the poster session.

Phytoremediation
Salt, D.E.; Smith, R.D.; and Raskin, I.
Annual Review of Plant Physiology and Plant Molecular Biology v 49 p 643(26) 1998

Phytoremediation, a cost-effective plant-based approach to remediation, takes advantage of the ability of plants to concentrate elements and compounds from the environment and to metabolize various molecules in their tissues. Several field trials have confirmed the feasibility of using plants for environmental cleanup. This review concentrates on the most developed subsets of phytoremediation technology and on the biological mechanisms that make phytoremediation work.

Phytoremediation: A Clean Transition from Laboratory to Marketplace?
Boyajian, G.E. and Carreira, L.H.
Natural Biotechnology v 15:2 p 127(2) 1997

In recent years, the potential of plants for environmental cleanup—phytoremediation—has been recognized, and U.S. government agencies and private corporations have responded by increasingly supporting research in this area. The report in this issue by Goel et al. both advances our basic knowledge of plant biochemistry and demonstrates that plants are indeed capable of tackling such exotic xenobiotic contaminants as nitroglycerin.

Phytoremediation: A New Technology Gets Ready to Bloom
Bishop, J.
Environmental Solutions v 10:4 p 29(6) May-June 1997

Phytoremediation is the use of selected crop plants or trees to extract or promote degradation of toxic substances in soils, ground water, surface water, wastewater and sediments. It may be possible in some cases to harvest such contaminants as heavy metals that have been taken up by plants and recover them for recycling. In other variations, plants stimulate the growth of naturally occurring microbial populations, which then degrade organic contaminants, such as petroleum hydrocarbons, in soils. At appropriate sites, the cost of applying phytoremediation techniques may range from half to less than 20% of the cost of using physical, chemical, or thermal techniques.

Phytoremediation Bibliography
Available at http://www.rtdf.org

This searchable bibliography of over 1,400 citations is the work of the EPA Phytoremediation Handbook Team in conjunction with the Remediation Technologies Development Forum (RTDF) Phytoremediation Action Team. The bibliography is updated frequently.

Phytoremediation Field Demonstrations in the U.S. EPA SITE Program
Rock, S. and Beckman, S.
In Situ and On-Site Bioremediation: Volume 3
Battelle Press, Columbus, OH p 323 [abstract only]
1998

U.S. EPA National Risk Management Research Laboratory's SITE program is evaluating phytoremediation's efficacy and cost at field scale demonstrations on sites in Oregon, Utah, Texas, and Ohio. The Superfund Innovative Technology Evaluation (SITE) Program is a part of EPA's research into alternative cleanup methods for hazardous waste sites. The EPA teamed with USAF, USGS, Ohio EPA, Chevron USA, Phytotech, Inc., and Phytokinetics, Inc. to accomplish these demonstrations. At a wood treater in Portland, Oregon, shallow soil contaminated with PCP and PAHs is being treated with a perennial ryegrass. In Ogden, Utah, a combination of poplar trees, juniper trees, alfalfa, and fescue has been planted to remediate a petroleum spill which has polluted both the soil and the ground water. On an Air Force facility near Fort Worth, Texas, cottonwood trees are being used to intercept a part of a large TCE ground water plume. In Ohio, the shallow soil of a former metal plating facility is the site for a demonstration of phytoextraction of lead, cadmium, and hexavalent chromium using Indian mustard. Each demonstration includes monitoring the soil, ground water, and plant material. The sites were planted in 1996, and will be monitored until at least 1999. [Abstract only. Additional information is available at http://clu-in.org under the SITE Demonstration Program page.]

Phytoremediation: It Grows on You
Boyajian, G. E. and Devedjian, D.L.
Soil & Groundwater Cleanup p 22(5) February-March 1997

Phytoremediation is a small but growing subset of *in situ* remediation technologies for contaminated soil. Plants can be effective remediators by reaching contaminants through their root systems, their ability to accumulate metals and degrade organic compounds, and their reduced cost compared with other approaches. However, only those plants having the appropriate biochemical pathways are effective for soil cleanup. Identification of appropriate plants for remediation of organic compounds and heavy metals is discussed.

Phytoremediation on the Brink of Commercialization
Watanabe, M.E.
Environmental Science & Technology v 31:4 p 182A(4) 1997

Academic, government, and corporate researchers have a body of data on the ability of certain plants to either remove pollutants from the environment or render them harmless, and they are looking for ways to improve these traits through plant breeding and molecular techniques. In the past three years, at least three new companies have formed to use plants to clean sites contaminated with heavy metals or organics. Phytoremediation is a natural process carried out by plants, especially those that are able to survive in contaminated soil and water. Hyperaccumulators are plants that can absorb high levels of contaminants with their roots and concentrate them either there or in shoots and leaves. Researchers have found hyperaccumulator species by collecting plants in areas where soil contains greater than usual amounts of metals or other potentially toxic compounds because of geological factors or pollution. Among the plants that have been collected and used in field trials are species from the genus *Thlaspi*, or Alpine pennycress, which accumulate zinc, cadmium, or lead, and *Alyssum* species, which accumulate nickel. Both genera belong to the mustard family *Brassicaceae*. Plants from other families also have been shown to remove cobalt, copper, chromium, manganese, or selenium from contaminated soils.

Phytoremediation: Technology Overview Report
Miller, R.
Groundwater Remediation Technologies Analysis Center, Pittsburgh, PA 26 pp 1996
Available at http://www.gwrtac.org

Phytoremediation uses plants to cleanup contaminated soil and ground water, taking advantage of plants' natural abilities to take up, accumulate, and/or degrade constituents of their soil and water environments. Research results report it to be applicable to a broad range of contaminants including numerous metals, radionuclides, and various organic compounds (such as chlorinated solvents, BTEX, PCBs, PAHs, pesticides/insecticides, explosives, nutrients, and surfactants). According to information reviewed, general site conditions best suited for use of phytoremediation include large areas of low to moderate surface soil (0 to 3 feet) contamination or large volumes of water with low-level contamination subject to low (stringent) treatment standards. Major advantages reported for phytoremediation as compared to traditional remediation technologies include the possibility of generating less secondary wastes, minimal associated environmental disturbance, and the ability to leave soils in place and in a usable condition following treatment. Cited disadvantages include the long lengths of time required (usually several growing seasons), depth limitations (3 feet for soil and 10 feet for ground water), and the possibility of contaminant entrance into the food chain through animal consumption of plant material.

Phytoremediation: Using Green Plants to Clean Up Contaminated Soil, Groundwater, and Wastewater
Negri, M. C. and Hinchman, R.R.
9 pp 1996

Phytoremediation, an emerging cleanup technology for contaminated soils, ground water, and wastewater that is both low-tech and low-cost, is defined as the engineered use of green plants to remove, contain, or render harmless such environmental contaminants as heavy metals, trace elements, organic compounds, and radioactive compounds in soil or water. Current research at Argonne National Laboratory includes a successful field demonstration of a plant bioreactor for processing the salty wastewater from petroleum wells and a greenhouse experiment on zinc uptake in hybrid poplar (*Populus* sp.). Because the roots sequester most of the contaminant taken up in most plants, a major objective of this program is to determine the feasibility of root harvesting as a method to maximize the removal of contaminants from soils. Available techniques and equipment for harvesting plant roots, including young tree roots, are being evaluated and modified as necessary for use.

Remediation Technologies Screening Matrix and Reference Guide
Federal Remediation Technologies Roundtable
Available at http://www.frtr.gov

This reference guide provides a "yellow pages" of remediation technologies. It is intended to be used to screen and evaluate candidate cleanup technologies for contaminated installations and waste sites in order to assist remedial project managers (RPMs) in selecting a remedial alternative. It incorporates cost and performance data to the maximum extent available and focuses primarily on demonstrated technologies. All levels of remediation technologies are included in this guide. These technologies are applicable at all types of site cleanups: Superfund, DoD, DOE, RCRA, state, private, etc.

Stemming the Toxic Tide
Dutton, G.
Compressed Air v 101:4 p 38(5) June 1996

Phytoremediation, the use of plants to clean up toxic substances in soil and water, has been proposed as an effective treatment for contaminated soil and sludge at industrial locations, including Superfund sites. The approach represents a cost-effective alternative to conventional remediation methods. Elements being considered as targets of phytoextraction include nickel, zinc, copper, selenium, cadmium, chromium, lead, cobalt, manganese, and several radionuclides. Specific plants and processes being used to clean soil and water are identified. Problems with the approach include disposal issues and time and depth limitations.

Technology Evaluation Report: Phytoremediation
Schnoor, J.L.
Ground-Water Remediation Technologies Analysis Center
43 pp October 1997
Available at http://www.gwrtac.org

Phytoremediation is best applied at sites with shallow contamination by organic, nutrient, or metal pollutants. Phytoremediation is well-suited for use at very large field sites where other methods of remediation are not cost-effective or practicable; at sites with low concentrations of contaminants where only "polishing treatment" is required over long periods of time; and in conjunction with other technologies where vegetation is used as a final cap and closure of the site. There are limitations to the technology that need to be considered carefully before it is selected for site remediation. These include: limited regulatory acceptance, long duration of time sometimes required for clean-up to below action levels, potential contamination of the vegetation and food chain, and difficulty establishing and maintaining vegetation at some toxic waste sites. This detailed report discusses the current status of phytoremediation to treat soils and ground water. Several field demonstration summaries are presented, with such information as: participants, compounds treated, site characteristics, results, and contacts.

Using Phytoremediation to Clean Up Contamination at Military Installations
Zellmer, S.D.; Hinchman, R.R.; Negri, M.C.; Schneider, J.F.; and Gatliff, E.G.
19 pp July 1997

NTIS Document Number: DE97007971

An emerging technology for cleaning contaminated soils and shallow ground water is phytoremediation, an environmentally friendly, low-cost, and low-tech process. Phytoremediation encompasses all plant-influenced biological, chemical, and physical processes that aid in the uptake, degradation, and metabolism of contaminants by either plants or free-living organisms in the plant's rhizosphere. A phytoremediation system can be viewed as a biological, solar-driven, pump-and-treat system with an extensive, self-extending uptake network (the root system) that enhances the soil and below-ground ecosystem for subsequent productive use. Argonne National Laboratory has been conducting basic and applied research in phytoremediation since 1990.

Publications Containing Multiple Papers

Phytoremediation of Soil and Water Contaminants
Kruger, E.L.; Anderson, T.A.; and Coats, J.R. (eds.)
Developed from a symposium sponsored by the Division of Agrochemicals and the Division of Environmental Chemistry at the 212th National Meeting of the American Chemical Society, August 25-29, 1996, Orlando, Florida.
American Chemical Society, Washington, DC 318 pp 1997

Emerging Technologies in Hazardous Waste Management VII: The 7th ACS Special Symposium, 17-20 September 1995, Atlanta, Georgia
Tedder, D.W. (ed.)
American Chemical Society, Washington, DC 1352 pp 1995

Bioremediation Through Rhizosphere Technology
Anderson, T.A. and Coats, J.R. (eds.)
American Chemical Society, Washington, DC 249 pp 1994

Bioremediation of Surface and Subsurface Contamination (Annals of the New York Academy of Sciences, Vol. 829)
Bajpai, R. and Zappi, M. (eds.)
1997

In Situ and On-Site Bioremediation, Vol. 3
Alleman, B.C. and Leeson, A. (eds.)
Battelle Press, Columbus, OH 570 pp 1997

Proceedings of the Annual Conference on Hazardous Waste Research
Great Plains/Rocky Mountain Hazardous Substance Research Center, Kansas State University, Manhattan, KS
Tables of contents, abstracts, and selected papers from the 1994 Ninth Annual Conference onward are available at http://www.engg.ksu.edu/HSRC

Proceedings of the International Seminar on Use of Plants for Environmental Remediation (ISUPER)
Council for Promotion of Utilization of Organic Materials (CPOUM), Kosaikan, Tokyo, Japan 1997

Annual International Conference on Phytoremediation
International Business Communications, Southborough, MA (1st:1996, 2nd:1997, 3rd:1998)

Proceedings of the 12th Annual Conference on Contaminated Soils: Analysis, Site Assessment, Fate, Environmental and Human Risk Assessment, Remediation and Regulation, 20-23 October 1997, Amherst, MA
Kostecki, P. T. and Calabrese, E.J. (eds.)
Environmental Health Sciences Program, School of Public Health, University of Massachusetts, Amherst, MA, 1997

Journal of Soil Contamination
v 7:4 July 1998

Soil & Groundwater Cleanup
February-March 1999

Soil & Groundwater Cleanup
February-March 1998

International Journal of Phytoremediation
First Issue (v 1:1) to be published by CRC Press in March 1999.

Phytoremediation
Terry, N. and Bañuelos, G.S. (eds.)
Ann Arbor Press, (In press. Release expected Summer 1999).

Superfund Innovative Technology Evaluation Program: Technology Profiles, 9th Edition

EPA Document Number: EPA 540-R-97-502

Organic Contaminants

Overviews

Mechanisms of Phytoremediation: Biochemical and Ecological Interactions Between Plants and Bacteria
Siciliano, S.D. and Germida, J.J.
Environmental Reviews v 6:1 p 65(15) 1998

This review concentrates on plant-bacteria interactions that increase the degradation of hazardous organic compounds in soil. Plants and bacteria can form specific associations in which the plant provides the bacteria with a specific carbon source that induces the bacteria to reduce the toxicity of the contaminated soil. Alternatively, plants and bacteria can form nonspecific associations in which normal plant processes stimulate the microbial community, which in the course of normal metabolic activity degrades contaminants in soil. Plants can provide carbon substrates and nutrients, as well as increase contaminant solubility. These biochemical mechanisms increase the degradative activity of bacteria associated with plant roots. In return, bacteria can augment the degradative capacity of plants or reduce the toxicity of the contaminated soil.

Phytoremediation of TCE in Groundwater using *Populus*
Chappell, J.
Status Report Prepared for the U.S. EPA Technology Innovation Office, 1997
Available at http://clu-in.org

This report is intended to provide a basic orientation to phytoremediation and a review of its use for shallow ground water remediation. It contains information gathered from a range of currently available sources, including project documents, reports, periodicals, Internet searches, and personal communication with involved parties. No attempts were made to independently confirm the resources used.

Field Studies and Demonstrations

Demonstration Plan for Phytoremediation of Explosive-contaminated Groundwater in Constructed Wetlands at Milan Army Ammunition Plant, Milan, Tennessee. Volumes 1 and 2. Final Report
Behrends, L.; Sikora, F.; Kelly, D.; Coonrod, S.; and Rogers, B.
209 pp (Vol. 1), 496 pp (Vol. 2) Jan 1996

NTIS Document Number: ADA311121/8/XAB (Vol. 1)
ADA311122/6/XAB (Vol. 2)

This plan demonstrates the technical and economic feasibility of using phytoremediation in an artificial, constructed wetlands for treatment of explosives-contaminated ground water at Milan Army Ammunition Plant. Validated data on cost and effectiveness of this demonstration will be used to transfer this technology to the user community.

Evaluation of Various Organic Fertilizer Substrates and Hydraulic Retention Times for Enhancing Anaerobic Degradation of Explosives-Contaminated Groundwater While Using Constructed Wetlands at the Milan Army Ammunition Plant, Milan, Tennessee
Behrends, L.L.; Almond, R.A.; Kelly, D.A.; Phillips, W.D.; and Rogers, W.J.
383 pp May 1998

NTIS Document Number: ADA349293

This document describes studies conducted at the Milan Army Ammunition Plant (MAAP) to improve the design, operation, and cost of gravel-based anaerobic cells when phytoremediating explosives-contaminated ground water. A typical gravel-based wetland consists of an anaerobic cell for removing the bulk of the explosive-contaminates, and an aerobic cell for removing CBOD-5, nutrients, total suspended solids, and small quantities of explosive by- products. The cells are connected in series with the anaerobic cell being the first cell. Small-scale anaerobic test cells were used to determine: (1) If the hydraulic retention time of a large demonstration-scale anaerobic cell at MAAP could be reduced, and (2) if other carbon sources could be used as an anaerobic feedstock. The study results indicate that: (1) The existing anaerobic cell's 7.5-day retention time should not be reduced since residual explosive by-products were present in the effluent of treatments with a 3.5-day retention time. (2) Daily application of a relatively soluble substrate, such as molasses syrup, will provide better explosives removal than periodic application of less soluble substrates such as milk replacement starter and sewage sludge.

Field Scale Evaluation of Grass-Enhanced Bioremediation of PAH Contaminated Soils
Sorensen, D.L.; Sims, R.C.; and Qiu, X.
EPA Risk Reduction Engineering Laboratory's 20th Annual Research Symposium, 15-17 March 1994, Cincinnati, OH p 92(3)

A field pilot-scale study was launched to assess the potential of prairie grasses to enhance bioremediation of PAH-contaminated soils. The ongoing research is designed to test the hypothesis that the deep, fibrous root system of the grasses improves aeration in soil and degradative capability in the rhizosphere. Average phenanthrene levels declined dramatically in both vegetated and unvegetated plots. Acenaphthylene also declined in both sites with time and was detected in higher concentrations in unvegetated shallow soil relative to vegetated shallow soil. Preliminary data indicate slow degradation in test plots and provide some evidence that Buffalo grass sod planting enhanced degradation in the near surface.

Friendly Forests
Miller, J. A.
Third International Conference on Health, Safety, Environment in Oil and Gas Exploration and Production, 9 June-12 Sep 1996, New Orleans, Louisiana
Society of Petroleum Engineers (SPE), Inc., Richardson, TX p 717(6) 1996

Trees can be used to extract ground water from aquifers and serve as a natural pumping system for contaminated ground water plume control. Simultaneously, the trees create a rhizosphere biodegradation zone and extract hydrocarbons through uptake in the transpiration stream. Phytoremediation has been proposed for cleanup of historical petroleum hydrocarbon and chlorinated hydrocarbon contamination as an *in situ* treatment method of reasonable cost that requires little maintenance. The initiative of one major oilfield service company at a Louisiana site is described. The demonstration began in June 1995 with the planting of 92 hybrid poplar trees for the purposes of (1) controlling ground water movement; (2) taking up constituents from soil and ground water; and (3) enhancing bioremediation of soil and ground water in the rhizosphere. Results to date are reported.

Groundwater Phytoremediation Test Facility, University of Washington
Contact: Stuart E. Strand, Research Associate Professor
Box 352100, College of Forest Resources, University of Washington, Seattle, WA 98195
Tel/Fax: 206-543-5350 E-mail: sstrand@u.washington.edu

The Ground water Phytoremediation Test Facility (GWPTF) was constructed in 1994 in Fife, Washington. The facility covers about one-quarter acre and is equipped with 12 double-lined test beds, each 12 ft x 18 ft x 4.5 ft deep. The site has equipment for handling, mixing, and delivering synthetically contaminated water and for decontaminating the effluent water using carbon adsorption units. The test facility has been used to provide the first near-full-scale testing of phytoremediation of chlorinated hydrocarbons in ground water. Results indicate nearly complete uptake of TCE and carbon tetrachloride by poplar trees with no detectable TCE or CT emissions. The GWPTF test beds allow easy monitoring of influent and effluent mass fluxes of chlorinated solvents. A permit is required to conduct demonstrations. Technology developers and the site manager work together to file the permit. It takes about six months to obtain a permit. State and local regulations apply. Permission to add injectants for remediation may be granted on a case-by-case basis.

Phreatophyte Influence on Reductive Dechlorination in a Shallow Aquifer Containing TCE
Lee, R.W.; Jones, S.A.; Kuniansky, E.L.; Harvey, G.J.; and Eberts, S.M.
Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds
Battelle Press, Columbus, OH p 263(6) 1998

At Carswell Field, Fort Worth Naval Air Station Joint Reserve Base in Texas, a phytoremediation demonstration project is being conducted to determine if eastern cottonwood trees are effective in remediating shallow trichloroethylene-contaminated ground water. Two tree plots were prepared and planted in April 1996, and baseline sampling began shortly thereafter. A stand of whips (cuttings) and a stand of 1- to 2-year-old trees are included in the study. After 18 months, the root systems were not sufficiently established to alter the chemistry and microbiology of the ground water. However, a nearby mature cottonwood tree was found to have changed ground water chemistry, causing oxygen consumption, iron reduction, methane production, and reductive dechlorination of TCE in the vicinity of the root system. Ground water levels and TCE concentrations in the aquifer will be monitored to establish baseline conditions and to map changes within the aquifer throughout the life of the demonstration. Costs associated with the planting and cultivation of each tree stand will be compared to help assess the practicability of phytoremediation as a cleanup technology. Demonstration sampling will continue until the year 2000.

Phytoremediation of Dissolved-Phase Trichloroethylene Using Mature Vegetation
Doucette, W.J.; Bugbee, B.; Hayhurst, S.; Plaehn, W.A.; Downey, D.C.; Taffinder, S.A.; and Edwards, R.
Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds
Battelle Press, Columbus, OH p 251(6) 1998

At a study site at Cape Canaveral Air Station, FL, transpiration gas and tissues of live oak, castor bean, and saw palmetto growing above a trichloroethylene (TCE)-contaminated ground water plume were collected and analyzed for TCE and its metabolites. Results showed that measurable levels of TCE were detected in seven of 15 transpiration-gas samples. Trichloroethylene, 2,2,2-trichloroethanol, 2,2,2-trichloroacetic acid, and 2,2-dichloroacetic acid were detected in all plant tissue types from all three species. Generally, metabolite concentrations were higher than TCE concentrations. Highest TCE concentrations were found in the roots, while highest metabolite concentrations were detected in leaf and stem samples.

Phytoremediation of Groundwater at Avesta Sheffield Pipe
Glanders, G.A. and Lundquist, J.B.
Iron and Steel Engineer v 75:5 p 39(3) May 1998

Ground water contaminated with volatile organic compounds and nitrate from spent pickle liquor is being remediated by a phytoremediation process using limpograss. Limpograss is a high protein, nitrate-loving grass that also serves as a valuable source of animal feed.

Phytoremediation of Organic and Nutrient Contaminants
Schnoor, J.L.; Licht, L.A.; McCutcheon, S.C.; Wolfe, N.L.; and Carreira, L.H.
Environmental Science & Technology v 29:7 p 318A(6) 1995

Phytoremediation, the use of vegetation for the *in situ* treatment of contaminated soils and sediments, is an emerging technology that promises effective and inexpensive cleanup of certain hazardous waste sites. Remediation using plants is best suited to sites with shallow contamination (<15 ft depth); moderately hydrophobic pollutants (BTEX compounds, chlorinated solvents, nitrotoluene ammunition wastes), or excess nutrients (nitrate, ammonium, and phosphate). The technology has been used effectively in a number of full-scale and pilot studies that are mentioned in the article.

Pilot-Scale Use of Trees to Address VOC Contamination
Compton, H.R.; Haroski, D.M.; Hirsh, S.R.; and Wrobel, J.G.
Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds

Battelle Press, Columbus, OH p 245(6) 1998
At the Aberdeen Proving Ground, MD, significant levels of VOCs have been detected in the ground water, primarily in the surficial aquifer, at depths to approximately 12 m. A study was conducted to assess phytoremediation as a viable alternative for remediating the shallow ground water contamination. Over a 4000-m^2 plot, 183 hybrid poplar trees were planted, and seasonal transpiration gas and water samples were analyzed. The data revealed that the trees were removing or degrading VOCs at the site as indicated by the presence of VOCs and their degradation products in transpiration gas, condensate, and leaf tissue. A gradient of ground water flow has formed toward the phytoremediation test plot, with a ground water depression of approximately 0.1 m. Analysis of nematode samples suggested that the soil habitat is improving due to the presence of the trees.

Screening of Aquatic and Wetland Plant Species for Phytoremediation of Explosives-Contaminated Groundwater from the Iowa Army Ammunition Plant. Final Report
Best, E.P.; Zappi, M.E.; Fredrickson, H.L.; Sprecher, S.L.; and Larson, S.L.
74 pp January 1997

NTIS Document Number: ADA322455/7/XAB

Munitions material such as 2,4,6-trinitrotoluene (TNT) and hexahydro-1,3,5- trinitro-1,3,5-triazine (RDX) and their combustion and decomposition products can enter the environment from production activities, field usage, and disposal. The capabilities of plants to absorb, accumulate, and metabolize, directly or indirectly, various organic substances suggest their use in the phytoremediation of contaminated environments.

Screening Submersed Plant Species for Phytoremediation of Explosives-Contaminated Groundwater from the Milan Army Ammunition Plant, Milan, Tennessee. Final Report
Best, E.P.; Sprecher, S.L.; Fredrickson, H.L.; Zappi, M.E.; and Larson, S.L.
89 pp November 1997

Phytoremediation systems are being considered as an alternative to other ground water extraction and surface treatment techniques due to their ability to enhance removal of potentially toxic or mutagenic munitions material such as 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5- trinitro-1,3,5-triazine (RDX), and their degradation products. This study evaluated the relative ability of ten species to decrease levels of TNT and RDX explosives and related contaminants in ground water at the Milan Army Ammunition Plant, Milan, Tennessee.

Research

Adsorption of Naphthalene onto Plant Roots
Schwab, A. P.; Al-Assi, A. A.; and Banks, M. K.
Journal of Environmental Quality v 27:1 p 220(5) January-February 1998

During phytoremediation, PAHs that are resistant to degradation may adsorb to the surfaces of plant roots, making the roots an important sink for specific PAHs. Tall fescue and alfalfa were grown in a greenhouse under controlled conditions, and roots were harvested at three growth stages: vegetative, flowering, and mature. Naphthalene adsorption to the various plant roots was then evaluated. Results show that the mass of naphthalene volatilized was the largest component of the mass balance (32-45%). The mass in solution was usually greater than that adsorbed to the roots. The affinity of naphthalene for alfalfa roots was greater than that for tall fescue roots, but fescue roots were present in much greater quantities in the soil compared with alfalfa. Naphthalene adsorption on the roots of both plant species increased with plant age.

Aromatic Nitroreduction of Acifluorfen in Soils Rhizospheres and Pure Cultures of Rhizobacteria
Zablotowicz, R.M.; Locke, M.A.; and Hoagland, R.E.
Agricultural Research Service September 1996

Reduction of the nitro group in acifluorfen (a nitrodiphenyl ether herbicide) to aminoacifluorfen is a major catabolic transformation of this herbicide in soils, rhizospheres, and pure cultures of certain bacteria. Aromatic nitroreduction occurs more rapidly in rhizosphere soils compared to root-free soil, with a rapid incorporation into unextractable humic soil components. Factors affecting acifluorfen-nitroreductase activity in cell suspensions and cell-free extracts of these bacteria were studied. Microbial aromatic nitroreductase activity in soils and rhizospheres can be an important biotransformation in the degradation of acifluorfen and other nitroaromatic herbicides.

Bacterial Inoculants of Forage Grasses That Enhance Degradation of 2-Chlorobenzoic Acid in Soil
Siciliano, S.D. and Germida, J.J.
Environmental Toxicology and Chemistry v16:6 p 1098(7) June 1997

A study was conducted to examine the potential of rhizosphere inoculants to enhance the degradation of contaminants in soil. 2-Chlorobenzoic acid was used as the model contaminant, along with 11 bacterial strains and 16 forage grass species. Results showed that three of the forage species—*Bromus biebersteinii*, *Elymus dauricus*, and *Agropyron riparum*—grew well in the 2-chlorobenzoic acid-contaminated soil and also enhanced the disappearance of the compound. The best bacterial inoculants proved to be *Pseudomonas aeruginosa* strain R75 and *P. savastoanoi* strain CB35. The inoculation of the forage grasses with either bacterial strain increased significantly the disappearance of 2-chlorobenzoic acid over that of unplanted controls.

Bioremediation Bacteria to Protect Plants in Pentachlorophenol-Contaminated Soil
Pfender, W.F.
Journal of Environmental Quality v 25:6 p 1256(5) November-December 1996

Pseudomonas strain SR3, a known pentachlorophenol-degrader, was added to a pentachlorophenol-contaminated soil, and the ability of the bacteria to protect Proso millet sown in the soil was assessed. Plants were removed from the soil 28 days after planting with roots, shoots, and soil analyzed for pentachlorophenol. Seedling emergence was found to be 50 and 62% for bacteria-treated and control seeds, respectively, in pentachlorophenol-contaminated soil. In uncontaminated soil, emergence rates were 100 and 87%, respectively. Bacterial treatment greatly increased final plant biomass in contaminated soil, bringing root and total plant weights to nearly the same as those observed for plants grown in uncontaminated soil. In contaminated soil planted with bacteria-treated seeds, the final pentachlorophenol level was only 3 mg/kg, as compared to 5 and 157 mg/kg for the millet-only and nonplanted contaminated soils, respectively.

Decreased Transpiration in Poplar Trees Exposed to 2,4,6-Trinitrotoluene
Thompson, P.L.; Ramer, L.A.; Guffey, A.P.; and Schnoor, J.L.
Environmental Toxicology & Chemistry v 17:5 p 902(5) May 1998

Poplar trees were exposed to 2,4,6-trinitrotoluene (TNT), and the effects on transpiration were examined. The TNT concentrations used were 0, 1, 3, 5, 10, and 15 mg/l. Levels of TNT uptake reached the detection limit of 4 ppm after only 1 hour of exposure, with TNT removed at a relatively rapid rate. TNT concentrations of greater than 5 mg/l were toxic to the trees, with the decrease in biomass attributed to the inhibition of leaf growth. This level decreased transpiration significantly after 11 days of exposure. Overall, the hybrid poplar exhibited a tolerance for TNT that was higher than that of duckweed and similar to that of yellow nutsedge.

Degradation of Polychlorinated Biphenyls by Hairy Root Culture of *Solanum nigrum*
Mackova, M.; Macek, T.; Kucerova, P.; Burkhard, J.; Pazlarova, J.; and Demnerova, K.
Biotechnology Letters v 19:8 p 787(4) August 1997

Hairy root cultures of *Solanum nigrum* proved capable of transforming PCBs under controlled conditions. The impact of several different plant growth regulators on cell growth and transformation of PCBs are analyzed. Plant cells proved capable of transforming PCBs even after growth had stopped. A 20% reduction in PCB conversion efficiency was observed in young inoculum (16 days), as compared against older inocula (37 and 68 days). The PCB transformation rate was stimulated with increasing size of inoculum.

Detoxification of Phenol by the Aquatic Angiosperm, *Lemna gibba*
Barber, J.T.; Sharma, H.A.; Ensley, H.E.; Polito, M.A.; and Thomas, D.A.
Chemosphere v 31:6 p 3567(8) September 1995

In many cases, plants have the ability to metabolize organic pollutants by transformation and conjugation reactions followed by compartmentalizing products in their tissues. The toxicity and fate of phenol in the angiosperm *Lemna gibba* were investigated. Over a 16 day growth period, almost 90% of the applied phenol disappeared from solution. While the disappearance of phenol was attributed to plant uptake, the appearance of additional compounds in the media indicated that metabolism occurred, with the release of the metabolites back to the media. The primary metabolite was identified as phenyl-(gr)b-D-glucoside, which was found to be approximately half as toxic as the parent compound.

Effect of Hybrid Poplar Trees on Microbial Populations Important to Hazardous Waste Bioremediation
Jordahl, J.L.; Foster, L.; Schnoor, J.L.; and Alvarez, P.J.J.
Environmental Toxicology and Chemistry v 16:6 p 1318(4) June 1997

Microbial populations from the rhizosphere of seven-year-old hybrid poplar trees were characterized in terms of five specific phenotypes: total heterotrophs; denitrifiers; pseudomonads; degraders of benzene, toluene, and xylenes (BTX); and atrazine degraders. The concentrations of these phenotypes were measured in three rhizosphere samples and in three control soil samples taken from an adjacent corn field. All types of microbial populations were higher in the poplar rhizosphere than in the surrounding soil. Highest concentrations were found for total heterotrophs, followed by denitrifiers, pseudomonads, BTX degraders, and atrazine degraders. These findings are discussed in relation to bioremediation potential.

Effects of Ryegrass on Biodegradation of Hydrocarbons in Soil
Gunther, T.; Friedrich-Schiller-Universitat J.; Dornberger, U.; and Fritsche, W.
Chemosphere v 33:2 p 203(13) July 1996

The influence of ryegrass on the biodegradation of applied aliphatics and PAHs was investigated using a series of laboratory soil-column experiments. A defined mixture of saturated, unsaturated, and branched-chain aliphatics and PAHs was added to the soil columns. Results show that the artificially applied aliphatic hydrocarbons disappeared faster and to a greater extent in ryegrass-planted columns than in the non-root systems. The enhanced disappearance of the pollutants in the rhizosphere was accompanied by higher values for microbial plate counts and soil respiration rates for the vegetated systems, which indicated the primary role of microbial degradation. In contrast to the aliphatics, the amount of PAHs decreased rapidly in both systems, and the differences between planted and unplanted soil were insignificant.

A Field Facility for Phytoremediation Research
Rhykerd, R.L.; Hallmark, M.T.; and Munster, C.L.
The 1998 ASAE Annual International Meeting, 11-16 July 1998, Orlando, Florida
American Society of Agricultural Engineers, St. Joseph, MI 1998

A recently developed phytoremediation computer model may be extremely useful in predicting the fate of recalcitrant hydrocarbons in soil. A field facility for phytoremediation research has been constructed to provide empirical data to validate and calibrate the model. Trinitrotoluene (TNT); 2,2',5,5'-tetrabromobiphenyl (PBB); and chrysene have been tested. Due to the hazardous nature of these hydrocarbons, the soil-contaminant mixture was isolated from the field environment using two lysimeter designs. Soil in both the box and column lysimeters were contaminated with 10 mg of each contaminant per kg of soil. Vegetation treatments consisted of fallow, warm season grass (Johnsongrass), cool season grass (Canadian wild-rye grass), and a warm/cool season grass rotation (Johnsongrass/Canadian wild-rye grass). Both the box and column lysimeters functioned well in collecting parameters necessary to validate and calibrate the computer model.

Greenhouse Evaluation of Agronomic and Crude Oil-Phytoremediation Potential Among Alfalfa Genotypes
Wiltse, C. C.; Rooney, W. L.; Chen, Z.; Schwab, A. P.; and Banks, M. K.
Journal of Environmental Quality v 27:1 p 169(5) January-February 1998

Twenty alfalfa plants were evaluated in terms of their agronomic performance and phytoremediation potential for crude oil-contaminated soil. Among the genotypes, differences were observed in total forage yield, maturity, plant height, and leaf-burn rating. Total petroleum hydrocarbon concentrations in soil after 12 months ranged 3799-5754 mg/kg for soils with the alfalfa plants and averaged 4610 mg/kg in the unvegetated control. When each genotype was considered separately, two genotypes had total petroleum hydrocarbon concentrations that were significantly lower than that of the unvegetated control. Plants growing in contaminated soil, however, exhibited later maturation and shorter heights than those growing in uncontaminated soil.

The Influence of Planting and Soil Characteristics on Mineralization of 2,4,5-T in Rhizosphere Soil
Boyle, J.J. and Shann, J.R.
Journal of Environmental Quality v 27:3 p 704(6) May-June 1998

Soils from an abandoned pasture, a forest, and a floodplain near Cincinnati, OH, were used as substrate for timothy grass, red clover, and sunflower, and evaluated in terms of their mineralization of 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Microbial activity, biomass, and mineralization of 2,4,5-T in rhizosphere soil were determined before and after planting. Results showed that microbial activity and biomass were dependent upon soil type in the unplanted plots. In soils with lower values, planting significantly increased biomass and/or activity, independent of plant species. Overall, soil type was the most significant determinant of microbial biomass, activity, and xenobiotic degradation.

Mineralization of 2,4-Dichlorophenol by Ectomycorrhizal Fungi in Axenic Culture and in Symbiosis with Pine
Meharg, A.A.; Cairney, J.W.G.; and Maguire, N.
Chemosphere v 34:12 p 2495(10) June 1997

The fungal mycelium associated with mycorrhizal plants provides a means of enhancing the volume of rhizospheric soil compared to bulk soil, which can enhance soil remediation. Two ectomycorrhizal fungal species—*Suillus variegatus* and *Paxillus involutus*—were evaluated in terms of their ability to degrade 2,4-dichlorophenol in batch culture and in association with *Pinus sylvestris*. Results indicate that 2,4-dichlorophenol was readily degraded by both species, but *P. involutus* proved to be much more efficient than *S. variegatus*. In the presence of pine seedlings, mycorrhizal symbiosis increased mineralization by both species, but the increase was much more dramatic for *S. variegatus*, which under these conditions became the more efficient degrader of 2,4-dichlorophenol.

Phytoremediation Experimentation with the Herbicide Bentazon
Conger, R.M. and Portier, R.J.
Remediation v 7:2 p 19(19) 1997

An experiment was performed on six species of trees to determine the feasibility of remediating ground water contaminated with an agricultural herbicide, bentazon, at a site in southern Louisiana. Fate studies on bentazon support that it is translocated to the plant leaves where it is degraded to lower-order derivative compounds within short periods of time. Both transpiration observations and dosing tests suggest that both the most favorable phreatophyte and species tolerant of bentazone exposure was the black willow (*Salix nigra*).

Phytoremediation: Modeling Removal of TNT and Its Breakdown Products
Medina, V.F. and McCutcheon, S.C.
Remediation v 7:1 p 31(15) Winter 1996

The success of phytoremediation techniques for the treatment of TNT-contaminated ground water and wastewater is evaluated. Two different phytoremediation techniques are examined: controlled reactors and constructed wetlands. The benefits offered by controlled reactors include: greater control over operating parameters, reduced chances of contaminant migration, and reduced chances that animals will feed on the plants. Constructed wetlands are generally less expensive and often provide aesthetic and ecological benefits. A first-order, nonreversible reaction, plug-flow, finite-difference model was used to predict the disappearance of TNT from a constructed wetland.

Phytoremediation of 1,4-dioxane by Hybrid Poplars
Aitchison, E.W.; Schnoor, J.L.; Kelley, S.L.; and Alvarez, P.J.J.
Proceedings of the 12th Annual Conference on Hazardous Waste Research, 20-22 May 1997, Kansas City, Missouri

The suspected carcinogen 1,4-dioxane has a half-life in soils and ground water of several years, while its half-life in the atmosphere in the presence of NO and hydroxyl radicals is several hours. The researchers examine 1,4-dioxane volatilization into the atmosphere via plant transpiration, evaluating the capacity of rooted cuttings of hybrid poplar trees to take up and translocate 1,4-dioxane. Study results indicate that poplar uptake of 1,4-dioxane far exceeds its degradation by indigenous root-zone microorganisms. The majority of 1,4-dioxane taken up into the plant was volatilized, with the remaining mass concentrated primarily in the stem. Rapid uptake of 1,4-dioxane by hybrid poplar trees makes phytoremediation an attractive treatment alternative at dioxane-contaminated sites, and research into this treatment methodology will continue.

Phytoremediation of Hazardous Wastes
McCutcheon, S.C.; Wolfe, N.L.; Carreria, L.H.; and Ou, T.Y.
Innovative Technologies for Site Remediation and Hazardous Waste Management: Proceedings of the National Conference, 23-26 July 1995, Pittsburgh, Pennsylvania
American Society of Civil Engineers, New York, NY p 597(8) 1995

Analyzing the effectiveness of phytoremediation involves rigorous pathway analyses, mass balance determinations, and identification of specific enzymes that break down trinitrotoluene (TNT), other explosives (RDX and HMX), nitrobenzene, and chlorinated solvents (such as TCE and PCE). For example, TNT is completely and rapidly degraded by nitroreductase and laccase enzymes. As part of the natural lignification process, the aromatic ring is broken and the carbon in the ring fragments is incorporated into new plant fiber. The use of created wetlands and other phytoremediation applications guided by rigorous field biochemistry and ecology promises to be a vital part of a newly evolving field, ecological engineering.

Phytoremediation of Organic Contaminants: A Review of Phytoremediation Research at the University of Washington
Newman, L.A.; Doty, S.L.; Gery, K.L.; Heilman, P.E.; et al.
Journal of Soil Contamination, v 7:4, p 531(12), 1998

Studies to determine the potential for phytoremediation of fully chlorinated compounds, brominated compounds, and nonhalogenated compounds are underway. When using phytoremediation, it is important to select not only a plant that is capable of degrading the pollutant in question, but also one that will grow well in that specific environment. One way to supplement the arsenal of plants available for remedial actions is to utilize genetic engineering tools to insert into plants those genes that will enable the plant to metabolize a particular pollutant. Hybrid technologies, such as using plants in pumping and irrigation systems, also enable plants to be used as a remedial method when the source of the pollutant is beyond the reach of plant roots, or when planting space directly over the pollutant is unavailable or restricted. Thus, the potential uses of phytoremediation are expanding as the technology continues to offer new, low-cost remediation options.

Phytoremediation of Pesticide-Contaminated Soils
Kruger, E.L.; Anderson, T.A.; and Coats, J.R.
Air & Waste Management Association's 89th Annual Meeting, 1996, Nashville, Tennessee
Available at http://www.awma.org

Screening tests of rhizosphere soils from 15 plant species were conducted to determine their ability to mineralize two common herbicide contaminants: atrazine and metolachlor. Mineralization of ^{14}C-atrazine or ^{14}C-metolachlor, applied at 50 ppm each, was monitored. Kochia rhizosphere soil exhibited the greatest mineralization of ^{14}C-atrazine. Other rhizosphere soils that exhibited the ability to mineralize high concentrations of atrazine included musk thistle, catnip, foxtail barley, witchgrass, and lambsquarters. None of the rhizosphere soils tested exhibited a positive response for ^{14}C-metolachlor mineralization. Mineralization of atrazine was considerable after 36 days, while mineralization of metolachlor was minimal. The percentage of extractable atrazine for kochia vegetated soils was significantly less than from nonvegetated soil. Combustion of plants revealed that 11% of the applied ^{14}C was taken up by kochia. This research indicates that the use of plants in remediating soils looks promising.

Phytoremediation of Trichloroethylene with Hybrid Poplars
Gordon, M.; Choe, N.; Duffy, J.; Ekuan, G.; Heilman, P.; Muiznieks, I.; Newman, L.; Ruszaj, M.; Shurtleff, B.B.; Strand, S.; and Wilmoth, J.
Phytoremediation of Soil and Water Contaminants
American Chemical Society, Washington, DC p 177(9) 1997

The ability of hybrid plants to absorb trichloroethylene (TCE) from ground water was examined. Initial studies used axenic tumor cultures of H11-11 grown in the presence of ^{14}C-TCE. These cells metabolized the TCE to produce trichloroethanol, di- and trichloroacetic acid. Some of the TCE was incorporated into insoluble, non-extractable cell residue, and small amounts were mineralized to $^{14}C-CO_2$. Rooted poplar cuttings grown in PVC pipes produced the same metabolites when exposed to TCE. Mass balance studies indicate that the poplars also transpire TCE. In addition one of the first controlled field trials for this technology is being conducted. Trees were planted in cells lined with high density polyethylene and exposed to TCE via an underground water stream during the growing season. Cells containing trees had significantly reduced TCE levels in the effluent water stream compared to control cells containing only soil. These results show that significant TCE uptake and degradation occur in poplars.

Phytoremediation, Plant Uptake of Atrazine and Role of Root Exudates
Burken, J.G. and Schnoor, J.L.
Journal of Environmental Engineering v 122:11 p 958(6) 1996

The potential of phytoremediation in the cleanup of contaminated sites and prevention of non-point-source pollution was examined with the pesticide atrazine in two experimental systems. Uptake was determined in batch experiments with ^{14}C ring-labeled atrazine and hybrid poplar trees grown in two soil types. Mineralization was studied utilizing soil microcosms with the addition of root exudates. Results indicate that poplar cuttings were able to uptake the majority of applied atrazine that was not tightly sorbed to the organic fraction of the soil, with no detectable adverse effects to the trees. The addition of root exudate to microcosms showed slight stimulation and the addition of ground-up root biomass revealed large stimulation of mineralization to $^{14}CO_2$. This research indicates that vegetative uptake and degradation in the rhizosphere can play a major role in remediation at hazardous waste sites.

Phytotreatment of TNT-Contaminated Groundwater
Rivera, R.; Medina, V.F.; Larson, S.L.; and McCutcheon, S.C.
Journal of Soil Contamination, v 7:4, p 511(20), 1998

Phytoremediation is a viable technique for treating munitions-contaminated ground water and wastewater. Continuous flow reactor studies were conducted at three different influent concentrations of 2,4,6-trinitrotoluene (TNT): 1, 5, and 10 ppm. Retention times varied from 12 to 76 days. Batch experiments were conducted to confirm the phytodegradation of amino-derivatives of TNT. Plant tissue was analyzed for TNT and breakdown products. Preliminary batch studies were also conducted on the degradation of RDX. Initially, the control removed TNT as efficiently as the plant reactors. However, as time continued, the efficiency of the control dipped below that of the plant reactors, suggesting that adsorption was initially the mechanism of removal. Up to 100% of the TNT was removed. Batch studies found that ADNT and diaminonitrotoluene (DANT) were phytodegraded. The batch studies indicated that the degradation of RDX was slower than that for TNT. Different plants were more efficient at removing RDX than those for removing TNT, suggesting that there are differences in the removal mechanisms.

Plant Cell Biodegradation of a Xenobiotic Nitrate Ester, Nitroglycerin
Goel, A.; Kumar, G.; Payne, G.F.; and Dube, S.K.
Natural Biotechnology v 15:2 p 174(4) 1997

The ability of plants to metabolize glycerol trinitrate (GTN, nitroglycerin), was examined using cultured plant cells and plant cell extracts. Intact cells rapidly degrade GTN with the initial formation of glycerol dinitrate (GDN) and the later formation of glycerol mononitrate (GMN). Cell extracts were shown to be capable of degrading GTN with the simultaneous formation of GDN in stoichiometric amounts. The degradative activities of plant cells are only ten times less than those reported for bacterial GTN degradation. These results suggest that plants may serve a direct degradative function for the phytoremediation of sites contaminated by organic nitrate esters.

Plant-Enhanced Remediation of Petroleum Contaminated Soil
Novak, J.T. and Al-Ghazzawi, Z.
Proceedings of the 1997 29th Mid-Atlantic Industrial and Hazardous Waste Conference
Technomic Publishing Co., Lancaster, PA p 605(9) 1997

Phytoremediation is an easy and inexpensive method for treating petroleum-contaminated soils. The phytoremediation mechanism is related to direct contaminant uptake or indirect plant mechanisms which catalyze pollutant-microbe interaction in the rhizosphere. These mechanisms and their importance are studied.

Plant-Enhanced Subsurface Bioremediation of Nonvolatile Hydrocarbons
Chang, Y.Y. and Corapcioglu, M.Y.
Journal of Environmental Engineering v 124:2 p 162(8) February 1998

Phytoremediation has become a promising new area of research for *in situ* cleanup of large volumes of slightly contaminated soils. A model that can be used as a predictive tool in phytoremediation operations was developed to simulate the transport and fate of a residual hydrocarbon contaminant interacting with plant roots in a partially saturated soil. Time-specific distribution of root quantity through soil, as well as root uptake of soil water and hydrocarbon, was incorporated into the model. In addition, the microbial activity in the soil rhizosphere was modeled with a biofilm theory. The simulation results showed enhanced biodegradation of a hydrocarbon contaminant mostly because of increased biofilm metabolism of organic contaminants in a growing root system of cotton. Simulations also show that a high mean daily root-water uptake rate increases the contaminant retardation factors because of the resulting low water content. The ability to simulate the fate of a hydrocarbon contaminant is essential in designing technically efficient and cost-effective, plant-aided remedial strategies and in evaluating the effectiveness of a proposed phytoremediation scheme.

Potential of Phytoremediation as a Means for Habitat Restoration and Cleanup of Petroleum Contaminated Wetlands
Lin, Q. and Mendelssohn, A.
Phytoremediation of Soil and Water Contaminants
American Chemical Society, Washington, DC 1997

Oil spills in coastal wetlands often kill vegetation and contaminate wetland sediment for many years. The potential of phytoremediation for habitat restoration and cleanup of contaminated marshes was studied with marsh mesocosms. Soil sods of *Spartina alterniflora* and *Spartina patens* (common coastal marsh grasses) were dosed with crude oil. Two years after application of the oil to the soil sods, these two *Spartina* species were transplanted into oiled and unoiled sods to determine the potential for habitat restoration and oil phytoremediation. The regrowth biomass was not significantly affected by oil for combined biomass of the two species and significantly higher with oil for *Spartina alterniflora*, suggesting the potential for habitat restoration by transplanting after oil spills. Oil degradation was enhanced by phytoremediation in combination with fertilization. The oil degradation rate was negligible in the absence of vegetation, but it was significantly higher in the presence of transplanted vegetation and fertilizer. Whether increased degradation of residual oil was due to the enhancement of soil microbial activity by the fertilizer or by phytoremediation is presently being investigated.

Rhizosphere Microbial Populations in Contaminated Soils
Nichols, T.D.; Wolf, D.C.; Rogers, H.B.; Beyrouty, C.A.; and Reynolds, C.M.
Water, Air, and Soil Pollution v 95:1-4 p 165(14) 1997

Rhizosphere microbial populations may enhance bioremediation of soil contaminated with organic chemicals. A growth chamber study was conducted to evaluate rhizosphere microbial populations in contaminated and non-contaminated soil. Alfalfa (*Medicago sativa L.*) and alpine bluegrass (*Poa alpina L.*) were grown in soil containing a mixture of organic chemicals for 14 weeks. The equal mixture of hexadecane, (2,2-dimethylpropyl)benzene, cis-decahydronaphthalene (decalin), benzoic acid, phenanthrene, and pyrene was added at levels of 0 and 2000 mg/kg. At nine weeks, the organic chemical degrader (OCD) populations were significantly higher in rhizosphere and contaminated soils than in bulk and non-contaminated soils. Selective enrichment of OCD populations was observed in contaminated rhizosphere soil. Higher numbers of OCD in contaminated rhizospheres suggest potential stimulation of bioremediation around plant roots.

Transformation of TNT by Aquatic Plants and Plant Tissue Cultures
Hughes, J. B.; Shanks, J.; Vanderford, M.; Lauritzen, J.; and Bhadra, R.
Environmental Science & Technology v 31:1 p 266(6) 1997

The ability of plants to uptake and transform 2,4,6-trinitrotoluene (TNT) was investigated using the aquatic plants *Myriophyllum spicatum*, axenic *Myriophyllum aquaticum*, and *Catharanthus roseus* hairy root cultures. Studies demonstrate that both *Myriophyllum* and *C. roseus* transform TNT. Primary products of transformation were not identified, and mineralization was not observed. Mass balances demonstrate that a large percentage of the unknown TNT transformation products were associated with the plant. This fraction could be at least partially recovered from the plant tissue with methanol extraction. A soluble fraction was also present in the medium. The formation of soluble, uncharacterized transformation products is a concern for potential phytoremediation applications.

Uptake and Fate of Organohalogens from Contaminated Groundwater in Woody Plants
Sytsma, L.; Mulder, J.; Schneider, J.; et al.
Proceedings of the 213th National Meeting of the American Chemical Society, 13-17 April 1997, San Francisco, California
American Chemical Society, Washington, DC p 89 1997

Phytoremediation uses green plants for low-cost, low-tech remediation processes in which selected plants and natural or engineered microorganisms work together to metabolize, convert, absorb, accumulate, sequester, or otherwise render harmless multiple environmental contaminants. There is evidence that plants can degrade a portion of many organic contaminants and form less volatile compounds which are sequestered in the plant tissue. The remainder of the contaminant is passed out of the leaf tissue with the transpiration stream. Hybrid poplar plants fed by TCE- and PCE-spiked nutrient solutions in a greenhouse showed elevated degradation product levels in the leaves within a week, as well as evidence for evapotranspiration of the TCE and PCE.

Publications Containing Multiple Papers

Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds: the First International Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, California, May 18-21, 1998
Wickramanayake, G.B. and Hinchee, R.E. (eds.)
Battelle Press, Columbus, OH 301 pp 1998

Inorganic Contaminants

Overviews

Emerging Technologies for the Remediation of Metals in Soils: Phytoremediation
Interstate Technology and Regulatory Cooperation Work Group (ITRC), Metals in Soils Work Team 15 pp 1998
Available at http://www.sso.org/ecos/itrc

Phytoremediation is a means of removing organic or inorganic contaminants from soils, sediments, and ground water using plants. This document focuses on issues related to the remediation of metals in soils. The technology, its applicability to sites and contaminants, and associated costs are outlined. Several approaches to phytoremediation are explored. The document also presents regulatory and stakeholder concerns and discusses research needs.

Literature Review: Phytoaccumulation of Chromium, Uranium, and Plutonium in Plant Systems
Hossner, L.R.; Loeppert, R.H.; Newton, R.J.; and Szaniszlo, P.J.
Amarillo National Resource Center for Plutonium, TX
53 pp May 1998

Phytoremediation is an integrated approach to the cleanup of contaminated soils that combines the disciplines of plant physiology, soil chemistry, and soil microbiology. Removal of metals from contaminated soils using accumulator plants is the goal of phytoremediation. The emphasis of this review has been placed on chromium (Cr), plutonium (Pu), and uranium (U). With the exception of Cr, these metals and their decay products exhibit two problems: radiation dose hazards and their chemical toxicity. Radiation dose hazards introduce the need for special precautions in reclamation beyond that associated with non-radioactive metals. The uptake of metals by plants occurs predominantly by way of channels, pores, and transporters in the root plasma membrane. Most vascular plants absorb toxic and heavy metals through their roots to varying degrees.

Remediation of Metal-Contaminated Sites Using Plants
Azadpour, A. and Matthews, J.E.
Remediation v 6:3 p 1(18) 1996

The current technologies employed for removal of heavy metals from soils often involve expensive *ex situ* processes requiring sophisticated equipment for removal, transportation, and purification of the soil. *In situ* bioremediation is receiving increasing attention because of its relative effectiveness and low cost. Phytoremediation, a new type of bioremediation, uses metal-tolerant hyperaccumulator plants to take up metal ions from soils and store them in the plant itself. To select the appropriate phytoremediation technology, the technical feasibility, cost effectiveness, and availability of the suitable plant species must be examined. Before phytoremediation can be exploited on a contaminated site, greenhouse-scale confirmatory testing is necessary to measure plant uptake and correlate shoot metal concentrations to available soil metals. These tests also validate that the harvesting and subsequent disposal of metal-containing plant tissues are environmentally safe and manageable.

Restoration of Mined Lands—Using Natural Processes
Bradshaw, A.
Ecological Engineering v 8:4 p 255(15) August 1997

In many countries legislation now requires that surface soils disturbed by mining activities be conserved and replaced, but there is a vast heritage of contaminated land left by past mining. The processes of natural succession demonstrate that unaided restoration can be achieved along with the development of fully functioning soils. Plants can readily provide organic matter, lower soil bulk density, bring mineral nutrients to the surface, and accumulate them in an available form. Most importantly, some species can fix and accumulate nitrogen rapidly in quantities more than adequate for normal ecosystem functioning. Certain extreme soil conditions may occur that prevent plant growth, particularly physical conditions, gross lack of certain nutrients, and toxicity. However, ecosystem restoration can be achieved at low cost, and the product be self-sustaining in the long term.

Status of *In Situ* Phytoremediation Technology
U. S. EPA, Office of Solid Waste and Emergency Response
Published in *Recent Developments for In Situ Treatment of Metal Contaminated Soils* p 31(12)

EPA Document Number: EPA 542-R-97-004

This chapter offers an overview of different phytoremediation approaches: phytoextraction, phytostabilization, and rhizofiltration, as well as a performance and cost summary, applications and future development analyses, and a list of metal hyperaccumulating plants.

Field Studies and Demonstrations

Phytoaccumulation of Trace Elements by Wetland Plants: *I. Duckweed*
Zayed, A.; Gowthaman, S.; and Terry, N.
Journal of Environmental Quality v 27:3 p 715(7) May-June 1998

The removal of trace elements by wetland vegetation is enhanced by the use of appropriate plant species. Results are presented from the first in a series of wetland-plant evaluations in terms of the removal of trace elements from contaminated water. Duckweed was considered for its phytoaccumulation of cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni), and selenium (Se). The data show that Cd was accumulated to the greatest levels, followed by Se, Cu, and Cr, and then Pb and Ni.

Relationship Between Sulfur Speciation in Soils and Plant Availability
Shan, X.-Q.; Chen, B.; Zhang, T.-H.; Li, F.-L.; Wen, B.; and Qian, J.
Science of the Total Environment v 199:3 p 237(10) 1997

Both bench-scale experiments and field surveys were conducted to investigate the relationship between sulfur speciation in soils and sulfur concentration in plants. Soil sulfur was fractionated into water-soluble sulfate (S_1), adsorbed sulfate (S_2), carbonate-occluded sulfate (S_3), ester sulfate (S_4) and carbon-bonded sulfur (S_5). Water-soluble sulfate was the most easily available form of soil sulfur, followed by adsorbed sulfate, ester sulfate, carbon-bonded sulfur and carbonate-occluded sulfate. Changes in concentrations of the different forms of soil sulfur after bench-scale experiments gave direct evidence to the order of availability. S_1 and S_2 decreased significantly, S_4 also decreased, whereas S_5 and S_3 remained almost unchanged. These results suggest that water-soluble and adsorbed sulfate are directly available to plants, while the mineralization of sulfate from organic sulfur, especially from ester sulfate, also contributes to plant uptake of sulfur.

Removal of Uranium from Water Using Terrestrial Plants
Dushenkov, S.; Vasudev, D.; Kapulnik, Y.; Gleba, D.; Fleisher, D.; Ting, K.C.; and Ensley, B.
Environmental Science & Technology v 31:12 p 3468(6) December 1997

Uranium (U) contamination of ground water poses a serious environmental problem in uranium mining areas and in the vicinity of nuclear processing facilities. Preliminary laboratory experiments and treatability studies indicate that the roots of terrestrial plants can be efficiently used to remove U from aqueous streams (rhizofiltration). Almost all of the U removed from the water in the laboratory using sunflower plants was concentrated in the roots. Rhizofiltration technology has been tested in the field with U-contaminated water at concentrations of 21—874 μg/L at a former U processing facility in Ashtabula, OH. The pilot-scale rhizofiltration system provided final treatment to the site source water and reduced U concentration to <20 μg/L before discharge to the environment. System performance was subsequently evaluated under different flow rates permitting the development of effectiveness estimates for the approach.

Research

Differences in Root Uptake of Radiocesium by 30 Plant Taxa
Broadley, M.R. and Willey, N.J.
Environmental Pollution v 97:1-2 p 11(5) 1997

The concentration of Cesium (Cs) was measured in the shoots of 30 plant taxa after exposing the roots to 0.1 μg/g radiolabelled Cs soil for 6 hours. The maximum accumulation differences were between *Chenopodium quinoa* and *Koeleria macrantha* (20-fold in Cs concentration and 100-fold in total Cs accumulated). The lowest Cs concentrations occurred in slow growing *Gramineae* and the highest in fast growing *Chenopodiaceae*. If radiocesium uptake by the *Chenopodiaceae* during chronic exposures shows similar patterns to those reported here after acute exposure, then the food contamination implications and the potential for phytoremediation of radiocesium contaminated soils using plants in this family may be worth investigating.

Enhanced Accumulation of Pb in Indian Mustard by Soil-Applied Chelating Agents
Blaylock, M.J.; Salt, D.E.; Dushenkov, S.; Zakharova, O.; Gussman, C.; Kapulnik, Y.; Ensley, B.D.; and Raskin, I.
Environmental Science & Technology v 31 p 860(6) 1998

Phytoremediation is emerging as a potential cost-effective solution for the remediation of contaminated soils. Because contaminants such as lead (Pb) have limited bioavailability in the soil, a means of solubilizing Pb in the soil and facilitating its transport to plant shoots is vital to the success of phytoremediation. Indian mustard (*Brassica juncea*) was used to demonstrate the capability of plants to accumulate high tissue concentrations of Pb when grown in Pb-contaminated soil. A concentration of 1.5% Pb in the shoots of *B. juncea* was obtained from soils containing Pb (600 mg/kg) amended with synthetic chelates such as EDTA. The accumulation of Pb in the tissue
corresponded to the concentration of Pb in the soil and the concentration of EDTA added to the soil. The accumulation of Cadmium, Copper, Nickel, and Zinc from contaminated soil amended with EDTA and other synthetic chelators was also demonstrated. The research indicates that the accumulation of metals in the shoots of *B. juncea* can be enhanced through the application of synthetic chelates to the soil, facilitating high biomass accumulation as well as metal uptake.

Evaluation of Tamarisk and Eucalyptus Transpiration for the Application of Phytoremediation
Tossell, R.W.; Binard, K.; Sangines-Uriarte, L.; Rafferty, M.T.; and Morris, N.P.
Bioremediation and Phytoremediation: Chlorinated and Recalcitrant Compounds
Battelle Press, Columbus, OH p 257(6) 1998

A greenhouse study was conducted to evaluate phytoremediation using tamarisk and eucalyptus at a site in East Palo Alto, CA, where the ground water was contaminated with arsenic. The initial study assessed whether the trees could tolerate arsenic and sodium found in the ground water and soil. Over the course of the study, tamarisk used significantly more water than eucalyptus, but eucalyptus water use was substantially higher than tamarisk when normalized to shoot mass. Water use by both species was substantially lower for trees exposed to high sodium treatments, but tamarisk was less affected than eucalyptus.

Feasibility of Using Plants to Assist in the Remediation of Heavy Metal Contamination at J-Field, Aberdeen Proving Ground, Maryland. Final Report
Jastrow, J.D.
29 pp November 1995

Interest in the development of *in situ* bioremediation technologies has grown substantially over the last decade. The purpose of this project was to investigate the potential for using plants to remediate soils contaminated with heavy metals. *Phragmites australis*, one of the dominant species in the Toxic Burning Pits (TBP) area and other contaminated sites within J-Field, appears to be both tolerant of heavy metal contaminated soil conditions and capable of producing large amounts of biomass. Consequently, this project has concentrated on characterizing heavy metal accumulation by *Phragmites australis* growing in the TBP area relative to soil concentrations and availabilities. This type of information is necessary to determine the feasibility of using this species to assist in the remediation of metal contaminated soils at J-Field.

Lead-Contaminated Sediments Prove Susceptible to Phytoremediation
Goldsmith, W.
Soil and Groundwater Cleanup p 15(3)
February/March 1998
[Also available at http://www.bioengineering.com under the title **Phytoremediation Potential for Lead-Contaminated River Sediments**]

Most conventional technologies for removal or capping of lead-contaminated river sediments are neither technically nor economically practicable. Engineered wetlands for removal of lead from riverine sediments appear to offer a sound approach to cleanup via phytoextraction followed by harvesting. Plants have been identified that grow in this type of environment and possess a documented ability to take up lead into leaves, roots, and stems. Recent research suggests that phytoremediation conducted over a period of years can offer significant benefits in sediment cleanup.

Lead Uptake and Effects on Seed Germination and Plant Growth in a Pb Hyperaccumulator *Brassica pekinensis Rupr.*
Xiong, Z.-T.
Bulletin of Environmental Contamination Toxicology v 60:2 p 285(7) February 1998

The ability of *Brassica pekinensis Rupr.* to hyperaccumulate lead could make it effective for the phytoremediation of contaminated soils. The effect of various concentrations of lead on the germination of seeds and growth of plants was investigated. Generally germination and growth of roots and shoots demonstrated dose-related inhibition. Bioaccumulation of lead in root, stem, and leaf was related to lead concentration in the growth medium. Roots bioconcentrated lead to between 27 and 34 times the concentration in growth medium. Stem and leaf bioconcentration ranged from four to seven times and two to three times, respectively. The shoot to root ratio of lead was 0.9 for this plant species, which compares well with other hyperaccumulators. High ratios allow lead concentrated in shoots to be easily removed by harvesting.

Metal Accumulation by Aquacultured Seedlings of Indian Mustard
Salt, D.E.; Pickering, I.J.; Prince, R.C.; Gleba, D.; Dushenkov, S.; Smith, R.D.; and Raskin, I.
Environmental Science & Technology v 31 p 1636(9) 1997

Indian mustard (*Brassica juncea* (L.) Czern) seedlings grown in aerated water were able to accumulate various metals from contaminated water over a range of environmentally relevant metal concentrations. Seedlings concentrated the divalent cations Lead(II), Strontium(II), Cadmium(II), and Nickel(II) 500-2000 times and concentrated monovalent Cesium(I) and hexavalent Chromium(IV) 100-250 times from contaminated water containing the competing ions Ca, Mg, K, SO_4, and NO_3. At the lowest Cadmium (Cd) concentration studied, Cd levels were reduced to below 10 ppb (μg/L). In the absence of competing ions, Cd accumulation in seedlings increased 47-fold. This suggests that a better understanding of the biological processes governing uptake and accumulation of Cd by seedlings should allow the application of modern genetic engineering techniques to improve their selectivity and capacity for Cd removal from waters containing high levels of competing ions. As a first step in this process, we have started to define the tissue and cellular localization of Cd, its accumulation rates and possible uptake mechanisms, and the role of intracellular chelates in Cd detoxification. Intracellular Cd accumulation in seedlings was mediated by saturable transport system(s) and inhibited competitively in shoots and non-competitively in roots by Ca^{2+}, Zn^{2+}, and Mn^{2+}. Phytochelatins, the Cd-binding peptides known to be involved in Cd resistance in mature plants, also accumulated in *B. juncea* seedlings exposed to Cd. Our results suggest that the use of aquacultured seedlings of *B. juncea* could provide a novel approach to the treatment of various metal-contaminated waste streams.

Phytoextraction of Cadmium and Zinc from a Contaminated Soil
Ebbs, S.D.; Lasat, M.M.; Brady, D.J.; Cornish, J.; Gordon, R.; and Kochian, L.V.
Journal of Environmental Quality v 26:5 p 1424(7) September-October 97

The phytoextraction ability of *Brassica juncea*, *B. napus*, and *B. rapa* toward cadmium (Cd) and zinc (Zn) in a contaminated soil was determined and compared to that exhibited by *Thlaspi caerulescens*, *Agrostis capillaris*, and *Festuca rubra*. Results showed that *T. caerulescens* achieved shoot Cd concentrations approximately ten times as great as those of the three *Brassica* species, while shoot Zn concentrations in *T. caerulescens* were approximately 2.5 times as great.

However, due to the significantly greater biomass produced by the *Brassica* species, this species was more effective in removing Zn and equally effective in removing Cd as *T. caerulescens*.

Phytoextraction of Zinc by Oat (*Avena sativa*), Barley (*Hordeum vulgare*), and Indian Mustard (*Brassica juncea*)
Ebbs, S.D.; and Kochian, L.V.
Environmental Science & Technology v 32:6 802(5) 1998

The success of phytoremediation depends on the selection of plant species and soil amendments that maximize contaminant removal. Indian mustard (*Brassica juncea*) has been shown to be effective in phytoextracting Zn, particularly after the synthetic chelate EDTA has been applied to the soil. However, the effectiveness of grass species for phytoremediation has not been addressed in great detail. A hydroponic screening of 22 grass species indicated that oat (*Avena sativa*) and barley (*Hordeum vulgare*) tolerated the high copper, cadmium, and zinc concentrations present in the solution and also accumulated elevated concentrations of these metals in the plant shoots. A hydroponic experiment comparing these two grasses to Indian mustard indicated that, although shoot Zn concentrations were greater for Indian mustard, the grasses were considerably more tolerant. The results of this experiment suggest that barley has a phytoremediation potential equal to, if not greater than, that for *B. juncea*.

Phytoextraction: the Use of Plants to Remove Heavy Metals from Soils
Kumar, P. B. A. N.; Dushenkov, V.; Motto, H.; and Raskin, I.
Environmental Science & Technology v 29:5 p 1232(7) May 1995

The process of phytoextraction, the use of plants to remove heavy metals from soils, generally requires the translocation of heavy metals to the easily harvestable shoots. Several cultivars of Indian mustard (*Brassica juncea*) were investigated for their ability to efficiently accumulate lead and other heavy metals. The *Brassica* species included *B. nigra*, *B. oleracea*, *B. campestris*, *B. carinata*, *B. juncea*, and *B. napus*. Results indicate that *B. juncea* and *B. nigra* had the highest metal-accumulating ability among the species tested. Shoot growth was only slightly affected by exposure to lead over the concentration range tested. For the other metals examined, chromium had the highest phytoextraction coefficient, followed by cadmium, nickel, zinc, and copper.

Phytofiltration of Hazardous Cadmium, Chromium, Lead and Zinc Ions by Biomass of *Medicago sativa* (Alfalfa)
Gardea-Torresdey, J.L.; Gonzalez, J.H.; Tiemann, K.J.; Rodriguez, O.; and Gamez, G.
Journal of Hazardous Materials v 57:1-3 p 29(11) 1998

Previous laboratory batch experiments of *Medicago sativa* (Alfalfa) indicated that the African shoots population had an appreciable ability to bind copper(II) and nickel(II) ions from aqueous solution. Batch laboratory pH profile, time dependency, and capacity experiments were performed to determine the binding ability of the African shoots for cadmium(II), chromium(III), chromium(VI), lead(II), and zinc(II). Batch pH profile experiments indicate that the optimum pH for metal binding is approximately 5.0. Time dependency experiments demonstrate that metal binding to the African alfalfa shoots occurred within 5 minutes. Binding capacity experiments revealed the following amounts of metal ions bound per gram of biomass: 7.1 mg Cd(II), 7.7 mg Cr(III), 43 mg Pb(II), 4.9 mg Zn(II), and 0 mg Cr(VI). The results from these studies will be useful in the use of phytofiltration to remove and recover heavy metal ions from aqueous solution.

Phytoremediation of a Radiocesium-Contaminated Soil: Evaluation of Cesium^{137} Bioaccumulation in the Shoots of Three Plant Species
Lasat, M.M.; Fuhrmann, M.; Ebbs, S.D.; Cornish, J.E.; and Kochian, L.V.
Journal of Environmental Quality v 27:1 p 165(5) January-February 1998

At Brookhaven National Laboratory's Hazardous Waste Management Facilities, the potential for cesium-137 (^{137}Cs) extraction from contaminated soil by three plant species was studied. In addition, the effect of applying ammonium nitrate to contaminated soil on ^{137}Cs extraction was evaluated. The plants used were Indian mustard, red root pigweed, and tepary bean. Results show that red root pigweed concentrated the highest level of ^{137}Cs in shoots, followed by Indian mustard and tepary bean. Red root pigweed also produced significantly more shoot biomass than the other two species. Ultimately, red root pigweed removed 30- to 60-fold more ^{137}Cs from the soil than either of the other two species. For red root pigweed and tepary bean, the addition of ammonium nitrate produced only a slight increase in the level of ^{137}Cs in shoots.

Phytoremediation of Lead-Contaminated Soils: Role of Synthetic Chelates in Lead Phytoextraction
Huang, J.W.; Chen, J.; Berti, W.R.; and Cunningham, S.D.
Environmental Science & Technology v 31:3 p 800(6) March 1997

Studies have shown that lead (Pb) is accumulated in the roots of plants if Pb is bioavailable in the growth media. However, Pb bioavailability is limited. The relative efficiencies of selected synthetic chelates in enhancing Pb phytoextraction were compared. Corn, pea, goldenrod, sunflower, and ragweed were used, in combination with the chelates, EDTA, HEDTA, DTPA, EGTA, and EDDHA. Results show that Pb in soil solution increased linearly with increasing levels of HEDTA added to a Pb-contaminated soil. In all plant species tested, there was a surge in shoot Pb concentrations in response to the application of HEDTA, with the highest shoot Pb concentrations found in pea, followed by corn and sunflower. When experiments were continued with pea and corn plants, Pb accumulation was highest in the presence of EDTA, followed in decreasing order by HEDTA, DTPA, EGTA, and EDDHA. The rank in the efficiency in enhancing total Pb accumulation in shoots was the same as that found in enhancing soil Pb desorption.

Phytoremediation of Selenium Laden Soils: A New Technology
Banuelos, G.S.; Ajwa, H.A.; Terry, N.; and Zayed, A.
Journal of Soil and Water Conservation v 52:6 p 426(5) November-December 1997

Selenium (Se) is naturally present in many soils around the U.S. High concentrations of Se may exert toxic impacts on plants and animals. The performance of several plant species (including canola, Indian mustard, birdsfoot trefoil, tall fescue, and kenaf) in phytoremediation projects aimed at reducing soil Se levels to below toxic concentrations are reviewed. The best plants for these types of projects include *Brassica* and *Astragalus* species.

Phytoremediation of Uranium-Contaminated Soils: Role of Organic Acids in Triggering Uranium Hyperaccumulation in Plants
Huang, J.W.; Blaylock, M.J.; Kapulnik, Y.; and Ensley, B.D.
Environmental Science & Technology v 32:7 p 2004(5) 1998

Uranium (U) phytoextraction, the use of plants to extract U from contaminated soils, is an emerging technology. In this research, the effects of various soil amendments on U desorption from soil to soil solution were investigated, physiological characteristics of U uptake and accumulation in plants were studied, and techniques to trigger U hyperaccumulation in plants were developed. Of the organic acids (acetic acid, citric acid, and malic acid) tested, citric acid was the most effective in enhancing U desorption and subsequent accumulation in plants. Shoot U concentrations of *Brassica juncea* and *Brassica chinensis* grown in a U-contaminated soil (total soil U, 750 mg/kg) increased from less than 5 mg/kg to more than 5000 mg/kg in citric acid-treated soils. These results suggest that U phytoextraction may provide an environmentally friendly alternative for the cleanup of U-contaminated soils.

Potential for Phytoextraction of ^{137}CS from a Contaminated Soil
Lasat, M.M.; Norvell, W.A.; and Kochian, L.V.
Agricultural Research Service, Beltsville, MD February 1998

Cesium-137 (^{137}Cs) is a long-lived by-product of nuclear fission. Phytoremediation of radiocesium-contaminated sites is impeded by the marked capacity of soils to tightly adsorb ^{137}Cs and limit its availability for plant uptake. Bioavailability testing of a number of soil extractants from an aged contaminated soil obtained from Brookhaven National Laboratory demonstrated that ammonium salts released a large portion of the radiocesium trapped in the soil. This same amendment greatly stimulated the bioaccumulation of ^{137}Cs in plant shoots. Use of the best performing plant species from a species selection trial (cabbage), in conjunction with amending the soil with ammonium nitrate, resulted in dramatic improvements in the accumulation of ^{137}Cs in plant shoots compared with the results of many previous published studies (10 to 300-fold improvement). These findings indicate that the phytoremediation of ^{137}Cs contaminated soils is a very promising cleanup technology.

Potential Remediation of ^{137}Cs and ^{90}Sr Contaminated Soil by Accumulation in Alamo Switchgrass
Entry, J.A. and Watrud, L.S.
Water, Air, and Soil Pollution v 104:3-4 p 339(14) June 1998

Alamo switchgrass was evaluated on its ability to remove cesium-137 and strontium-90 from contaminated soil. Results show that the above-ground biomass of the plants accumulated 36% of the cesium-137 and 44% of the strontium-90 in the growth medium. However, the accumulated concentrations in the plants declined after two harvests. For both radionuclides, the duration of exposure correlated curvilinearly with accumulation by the plants. As the concentration of both radionuclides increased in the growth medium, total seedling accumulation and concentration of radioisotopes in plant tissue also increased curvilinearly. The overall findings revealed that Alamo switchgrass may be a good candidate species for remediating radionuclide-contaminated soils.

Rhizofiltration: the Use of Plants to Remove Heavy Metals from Aqueous Streams
Dushenkov, V.; Kumar, P. B. A. N.; Motto, H.; and Raskin, I.
Environmental Science & Technology v 29:5 p 1239(7) May 1995

Rhizofiltration is the use of plants to remove heavy metals from aqueous streams. Hydroponically grown roots of Indian mustard (*Brassica juncea*) were investigated for their ability to remove lead, cadmium, copper, chromium, nickel, and zinc from solution. The rate of lead removal depended on the initial concentration in solution and showed a monotonic decline with time. Since the magnitude of lead removal was proportional to the root weight, much faster removal rates were achieved when a larger root mass was used. Significant removal rates were also seen for the other metals. Only live roots were able to remove metals from solution.

The Role of EDTA in Pb Transport and Accumulation by Indian Mustard
Vassil, A.D.; Kapulnik, Y.; Raskin, I.; and Salt, D.
Plant Physiology v 117 p 447(7) 1998

Indian mustard (*Brassica Juncea*) plants exposed to lead (Pb) and EDTA in hydroponic solution were able to accumulate up to 55 mmol/kg Pb in dry shoot tissue (1.1%[w/w]). This represents a 75-fold concentration of Pb in shoot tissue over that in solution. A threshold concentration of EDTA (0.25 mmol) was found to be required to stimulate this dramatic accumulation of both Pb and EDTA in shoots. The majority of Pb in these plants is transported in coordination with EDTA. Exposure of Indian mustard to high concentrations of Pb and EDTA caused reductions in both the transpiration rate and the shoot water content. The onset of these symptoms was correlated with the presence of free protonated EDTA (H-EDTA) in the hydroponic solution, suggesting that free H-EDTA is more phytotoxic than Pb-EDTA. These studies clearly demonstrate that coordination of Pb transport by EDTA enhances the mobility within plants of this otherwise insoluble metal ion, allowing plants to accumulate high concentrations of Pb in shoots. The finding that both H-EDTA and Pb-EDTA are mobile within plants also has important implications for the use of metal chelates in plant nutritional research.

A Search for Lead Hyperaccumulating Plants in the Laboratory
Ghosh, S.; and Rhyne, C.
Agriculture and Plant Science Meeting, Mississippi State University, 1997

The research objective is to identify plant species capable of sustained healthy growth in elevated lead concentrations and to evaluate their effectiveness in accumulating high levels of lead in various parts of the plants. A modified hydroponic growing system was used to suspend plants in aqueous solutions of either Hoagland's nutrient medium or varying concentrations of $Pb(NO_3)_2$ in the laboratory. Thirty-three different plant species were tested and grouped into five categories based on their growth potential and lead uptake. Two plant species, *Ipomoea lacunosa* and *Sesbania exaltata*, appear to have significant potential as lead hyperaccumulators. After the desired exposure period, plants were harvested and separated into leaves, stems and roots to analyze and locate the accumulation of lead in different plant parts. Morphological characteristics (height and dry weight) of the plants were also observed.

Selenium Accumulation by *Brassica Napus* Grown in Se-laden Soil from Different Depths of Kesterson Reservoir
Banuelos, G.S.; Ajwa, H.A.; Wu, L.; and Zambrzuski, S.M.
Agricultural Research Service, Beltsville, MD August 1997

Elevated levels of selenium (Se) have been measured in sediment at Kesterson Reservoir and contributed to the death and deformities observed in waterfowl frequenting this site. As part of a remediation strategy to lower levels of soil Se, canola was planted in Se-contaminated sediment collected from the Reservoir, as well as on-site. Canola lowered Se concentrations more effectively under greenhouse conditions than in the field. The study clearly shows that extrapolating results from greenhouse to field conditions should be done with caution. Using canola to lower Se levels at Kesterson Reservoir will be a long-term management strategy under field conditions.

Test Plan for the Phytoremediation Studies of Lead-Contaminated Soil from the Sunflower Army Ammunition Plant, Desoto, Kansas. Vol. 1 and Vol. 2
Behel, D.; Kelly, D.; Pier, P.; Rogers, B.; and Sikora, F.
233 pp (v 1), 291 pp (v 2) October 1996

NTIS Document Number: ADA342667 (vol. 1)
ADA342668 (vol. 2)

This document provides a test plan for studying and improving techniques for remediating lead-contaminated soils using phytoremediation. It also discusses a study to examine the uptake of lead by plants in contaminated soil.

Toxicity of Zinc and Copper to *Brassica* Species: Implications for Phytoremediation
Ebbs, S.D. and Kochian, L.V.
Journal of Environmental Quality v 26:3 p 776(6) 1997

The toxicity of Zn and Cu in three species from the genus *Brassica* was examined to determine if these plants showed sufficient tolerance and metal accumulation to phytoremediate a site contaminated with these two heavy metals. Hydroponically grown 12 day-old plants of *Brassica juncea*, *B. rapa*, and *B. napus* were grown for an additional 14 days in the presence of either elevated Zn (6.5 mg/L), Cu (0.32 mg/L), or Zn plus Cu to quantify the toxic effects of these metals on several different growth parameters. With few exceptions, both root and shoot dry weight for all three species decreased significantly in the presence of heavy metals. In terms of heavy metal removal, the *Brassica* species were more effective at removing Zn from the nutrient solution than Cu. The extent of Zn and Cu removal was reduced when both metals were present as compared to the single heavy metal treatments. The implications of these results for phytoremediation are discussed.

Toxic Mercury Reduction and Remediation Using Transgenic Plants with a Modified Bacterial Gene
Rugh, C.L.; Gragson, G.M.; Meagher, R.B.; and Merkle, S.A.
University of Georgia, Athens, GA
HortScience v 33:4 p 618(4) July 1998

The objective of this paper is to give a brief overview of the concepts and progress of microbial- and plant-assisted pollution remediation research. A summary of efforts to genetically engineer plants for mercury reduction and detoxification, as well as considerations for future research toward this goal, will be presented.

Zinc and Cadmium Accumulation in the Hyperaccumulator *Thlaspi Caerulescens* in Response to Limestone and Compost Applications to a Heavy Metal Contaminated Site in Palmerton, Pennsylvania
Li, Y.M.; Chaney, R.L.; Kershner, B.A.; Chen, K.Y.; Angle, J.S.; and Baker, A.J.
Agricultural Research Service, Beltsville, MD
September 1997

Research is being conducted to develop a new technology using plants to remove Zn and Cd from contaminated soils which require remediation. *Thlaspi caerulescens* is a perennial herb which accumulates Zn (>3%) from soils to much higher foliar levels than economic crops. At the Palmerton, PA site, soil metal concentrations are very high and the soils are non-calcareous. It is likely that *Thlaspi* may suffer Zn phytotoxicity. Studies were conducted to characterize the long term effect of limestone and compost applications on plant biomass and Zn and Cd accumulation. In addition, the uptake of metals by hyperaccumulator *T. caerulescens* was compared to uptake by a local metal-tolerant species, Merlin red fescue. In this paper, we report that compost treatment reduced metal phytotoxicity. We have also determined that higher soil pH and organic matter were the important factors attributing to the large shoot biomass accumulation for *Thlaspi.*

Publications Containing Multiple Papers

Metal-Contaminated Soils: *In Situ* Inactivation and Phytorestoration
Vangronsveld, J. and Cunningham, S. (eds.)
R.G. Landes, Austin, TX

Bioremediation of Inorganics, Vol. 3
Hinchee, R.E.; Means, J.L.; and Burris, D.R. (eds.)
Battelle Press, Columbus, OH 184 pp 1995

Plants That Hyperaccumulate Metals: Their Role in Phytoremediation, Microbiology, Archaeology, Mineral Exploration, and Phytomining
Brooks, R. R. (ed.)
CAB International, New York

Internet Resources

Advanced Applied Technology Demonstration Facility (AATDF)
http://www.ruf.rice.edu/~aatdf

AATDF is a research facility funded by the Department of Defense, Army Corps of Engineers, Waterways Experiment Station (WES) through the Energy and Environmental Systems Institute at Rice University. One of its long-term projects involves evaluating and recommending innovative treatment technologies in support of faster and cheaper remediation.

Air Force Center for Environmental Excellence (AFCEE)
http://www.afcee.brooks.af.mil

The Air Force Center for Environmental Excellence provides a complete range of environmental, architectural, and landscape design, planning and construction management services and products. Environmental restoration is one of its several business lines, and its services include: studies and investigations, project design, cleanup, long-term operation/monitoring, program support, and new restoration technology research. It was formed in 1991.

Alternative Treatment Technology Information Center (ATTIC)
http://www.epa.gov/attic

The EPA Office of Research and Development (ORD) Alternative Treatment Technology Information Center (ATTIC) is a comprehensive computer database system providing up-to-date information on innovative treatment technologies. ATTIC provides access to several independent databases as well as a mechanism for retrieving full-text documents of key literature. The system provides information to make effective decisions on hazardous waste clean-up alternatives.

CLU-IN: Hazardous Waste Clean-Up Information
http://clu-in.org

The Hazardous Waste Clean-Up Information (CLU-IN) Web Site provides information about innovative treatment technologies to the hazardous waste remediation community. It describes programs, organizations, publications, and other tools for federal and state personnel, consulting engineers, technology developers and vendors, remediation contractors, researchers, community groups, and individual citizens. The site was developed by the U.S. EPA but is intended as a forum for all waste remediation stakeholders.

Environmental Security Technology Certification Program (ESTCP)
http://www.estcp.org

ESTCP's goal is to demonstrate and validate promising, innovative technologies that et the Department of Defense's (DoD's) most urgent environmental needs. These technologies provide a return on investment through cost savings and improved efficiency. The current cost of environmental remediation and regulatory compliance in the Department is significant. Innovative technology offers the opportunity to reduce costs and environmental risks. ESTCP's strategy is to select lab-proven technologies with broad DoD and market application. These projects are aggressively moved to the field for rigorous trials that document their cost, performance, and market potential. Successful demonstration leads to acceptance of innovative technologies by DoD end-users and the regulatory community.

Federal Remediation Technologies Roundtable
http://www.frtr.gov

The mission of the Roundtable is to exchange information and provide a forum for joint activity regarding the development and demonstration of innovative technologies for hazardous waste site remediation. The exchange synthesizes the technical knowledge that Federal Agencies have compiled and provides a more comprehensive record of performance and cost. Members include major developers and users of these technologies: Department of Defense (U.S. Army, U.S. Army Corps of Engineers, U.S. Navy, U.S. Air Force), U.S. Department of Energy, U.S. Department of the Interior, and the U.S. Environmental Protection Agency.

GNET: The Global Network of Environment and Technology
http://www.gnet.org

GNET® is an on-line global information center for environmental technology. The site contains an interactive environmental technology database (TechKnow) that houses information on phytoremediation and over 1,500 other technologies.

Great Plains/Rocky Mountain Hazardous Substance Research Center
http://www.engg.ksu.edu/HSRC

Kansas State University leads a fourteen-institution consortium for the Great Plains/ Rocky Mountain Hazardous Substance Research Center. The other member institutions are Lincoln, Haskell Indian Nations, Colorado State, Montana State, South Dakota State, and Utah State Universities, along with the universities of Iowa, Northern Iowa, Missouri, Montana, Nebraska, Utah, and Wyoming. The center was established in 1989 to conduct research pertaining to hazardous substances produced through agriculture, forestry, mining, mineral processing, and other activities of local interest. It serves Federal Regions 7 and 8. Specific research projects focus on soil and water contaminated by heavy metals from mining wastes and other industrial activities, soil and ground water contaminated by organic chemicals, wood preservatives that contaminate ground water, pesticides identified as hazardous substances, improved technologies and methods for characterizing and analyzing contaminated soil, and waste-minimization and pollution-prevention methods and technologies. The tables of contents, abstracts, and selected papers of the Proceedings of the Annual Conference on Hazardous Waste Research beginning with the Ninth Annual Conference (1994) onward may also be viewed at the Web site.

Ground Water Remediation Technologies Analysis Center (GWRTAC)
http://www.gwrtac.org

The Ground Water Remediation Technologies Analysis Center (GWRTAC) is a focal point for the collection and analysis of information on ground water remediation. The members of GWRTAC compile, analyze, and disseminate information on innovative ground water remediation technologies. Technical teams are selectively chosen from Concurrent Technologies Corporation (CTC), the University of Pittsburgh, and other supporting institutions.

Innovative Treatment Remediation Demonstration (ITRD)
http://www.em.doe.gov/itrd

The Innovative Treatment Remediation Demonstration (ITRD) Program is funded by the DOE Office of Environmental Restoration (EM-40) to help accelerate the adoption and implementation of new and innovative remediation technologies. Developed as a Public-Private Partnership program with Clean Sites, Inc., and the Environmental Protection Agency's (EPA) Technology Innovation Office (TIO) and coordinated by Sandia National Laboratories, the ITRD Program attempts to reduce many of the classic barriers to the use of new technologies by involving government, industry, and regulatory agencies in the assessment, implementation, and validation of innovative technologies.

Interstate Technology and Regulatory Cooperation Working Group (ITRC)
http://www.sso.org/ecos/itrc

The Interstate Technology and Regulatory Cooperation Working Group (ITRC) was established in December, 1994 by the Develop On-Site Innovative Technology Committee, referred to as the DOIT Coordinating Group of the Western Governors Association. The Mission of the ITRC is to facilitate cooperation among states in the common effort to test, demonstrate, evaluate, verify and deploy innovative environmental technology, particularly technology related to waste management, site characterization and site cleanup. Regulators from 24 states are collaborating with representatives from federal agencies, industry, and stakeholder groups to raise the comfort level of environmental decision makers about using new technologies. By pooling their experience and knowledge in permitting innovative technologies and by publishing and distributing their work products, ITRC is making it easier for state regulatory agencies to approve new technologies.

PHYTONET - Phytoremediation Electronic Newsgroup Network
http://www.dsa.unipr.it/phytonet

The Phytonet Newsgroup was developed to allow easy worldwide communications between scientists who work on problems related with Phytoremediation and Application of Plant Systems to Environmental Control. The Phytoremediation Electronic Network, moderated by Nelson Marmiroli, is operated by the Department of Environmental Sciences, University of Parma, Italy.

Remediation Technologies Development Forum (RTDF)
Phytoremediation of Organics Action Team
http://www.rtdf.org/public/phyto

The Phytoremediation of Organics Action Team was established in 1997, as one of seven Action Teams under the Remediation Technologies Development Forum (RTDF). The Phytoremediation of Organics Action Team includes representatives from industry and government who share an interest in further developing and evaluating the of use of plants and trees to remediate contaminated soil and water.

Strategic Environmental Research and Development Program (SERDP)
http://www.serdp.gov

The Strategic Environmental Research and Development Program is the Department of Defense's (DoD) corporate environmental R&D program, planned and executed in full partnership with the Department of Energy (DOE) and the Environmental Protection Agency (EPA), with participation by numerous other federal and non-federal organizations. Within its broad areas of interest, the Program focuses on Cleanup, Compliance, Conservation, and Pollution Prevention technologies.

U.S. Army Corps of Engineers Phytoremediation Research
http://www.wes.army.mil/EL/phyto

The U.S. Army Corps of Engineers Innovative Technology Program mission is to inform, encourage, promote, and support the development and use of innovative technology for environmental investigation and remediation. Its Phytoremediation Research site is part of the Waterways Experiment Station Environmental Laboratory Web site.

U.S. Army Environmental Center (USAEC)
http://aec-www.apgea.army.mil:8080

The USAEC Technology link provides access to descriptions of innovative restoration technology demonstrations conducted at numerous Army installations.

U.S. Department of Agriculture (USDA)
http://www.usda.gov

In addition to supporting research to improve agricultural production, the USDA also supports research concerning remediation of soil and ground water contaminated with pesticides, herbicides, and fertilizers. The Current Research Information System (CRIS) database is a documentation and reporting system for ongoing and recently completed research projects. The Technology Transfer Automated Retrieval System (TEKTRAN) provides abstracts of research results from the UDSA's Agricultural Research Service that will be published as articles or documents.

CRIS: http://cristel.nal.usda.gov:8080
TEKTRAN: http://www.nal.usda.gov/ttic/tektran